EVALUATION OF AN EVAPOTRANSPIRATION MODEL

FOR CORN AND SORGHUM

by

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Dedicated to

My family, Tom, and friends
for their love and support.

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CHAPTER I

INTRODUCTION

INTRODUCTION

Irrigation in sub-humid and semiarid regions increases agricultural production dramatically, but the practice becomes more and more expensive as water and fuel supplies are depleted. Nearly one million hectares in western Kansas are irrigated, generating at least $.5 billion per year in additional crop production and stimulating over $3 billion per year in economic activity (Governor's Task Force, 1977). The western part of the state depends on irrigated production to maintain vigorous and stable economic activity; that economy would suffer should water or fuel supplies limit irrigated production.

Until the 1950's, irrigation in western Kansas was limited, with the water supplied primarily from surface rivers and streams. Development of deep-well turbine pumps and availability of inexpensive natural gas made development of large groundwater supplies for irrigation possible, and the drought of the mid-1950's triggered a phenomenal growth in irrigation development (Governor's Task Force, 1977). By 1966, .5 million hectares were irrigated in the state using 2.8 billion cubic meters of water per year (or 68% of the state's water use). By 1980, the Kansas Water Resources Board projects 7.9 billion cubic meters of water will be used each year for irrigation (Kansas Water Resources Board, 1972).

The major source of water for irrigation in Kansas and for most of the High Plains region, is the Ogallala formation. Large quantities of water were stored during deposition of sediments during the Pliocene time (20 million years ago). This stored water is currently being mined to sustain irrigated agriculture, with recharge at the surface being quite small. The aquifer is quite variable, ranging from a few meters to 180 meters of saturated thickness, lying from near the surface to about 48 meters below the surface. The variability of the formation complicates

management of this water resource, but management is essential for prolonged life of the aquifer. The depth of the water table dropped up to 40 meters between 1950 and 1975 in some areas of Kansas. More than 50% of the original resource has been depleted in certain critical areas. In southwestern Kansas, there has been a 30 to 150 centimeter per year drop in the water table over most of the area, with an increase in the rate of decline noticeable in the past 5 to 10 years (Governor's Task Force, 1977).

As the water table drops, more fuel is required to pump the remaining water to the surface. Fuel supplies for irrigation are becoming scarcer and more expensive since the mid-1970's. As fuel and water supplies are depleted, irrigators and water management organizations realize that water pumpage for irrigation must be reduced.

In the past, many irrigators viewed water as a plentiful and inexpensive resource and accepted inefficiency in their irrigation system design, for economic reasons. Water is often applied liberally throughout the growing season to ensure that adequate water is supplied to the crop. Recent studies (Stone, 1977; Lewis et al., 1974; Vandia and Waisel, 1967; Denmead and Shaw, 1960; Blum, 1974; and Sumayao et al., 1977) have indicated that limited irrigation can be applied without reducing the physiological processes or yield of the crop. Irrigators are anxious to adopt limited irrigation practices, because while irrigation costs have soared, crop prices have not increased, so economically sound irrigation requires careful farm management practices. To successfully irrigate a crop with a limited water supply, an irrigator needs to know the crop's response to the soil moisture supply as well as the soil moisture status of the fields. Water is then applied, as necessary, to avoid yield-reducing stress, without applying excessive water to the field.

The moisture status of the soil can be monitored throughout the growing season by physically probing the soil profile or through the use of soil moisture sensing devices. These methods do not, however, provide information about the rate of water use by the crop because the information gained by these methods is generally qualitative rather than quantitative. Many researchers (Jensen et al, 1970 and 1971; Kanemasu et al, 1976; Ritchie, 1972: van Bavel, 1966; and others) have proposed evapotranspiration (ET) models which estimate the rate of water use by the crop and can be used to maintain a soil moisture balance. These models do not require excessive field monitoring by the irrigator during the irrigation season and are well adapted for regional water-use management programs.

Only through careful management of our water and fuel resources can we maintain productive irrigated agriculture in arid and semi-arid regions. This study was designed to examine the application of Kanemasu's (1976) evapotranspiration model to an irrigation scheduling program in southwestern Kansas.

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CHAPTER II

ESTIMATING EVAPOTRANSPIRATION FOR IRRIGATION SCHEDULING A LITERATURE REVIEW

2.1 ESTIMATING EVAPOTRANSPIRATION

In sub-humid to arid climates, irrigation often supplies part or all of the water necessary for agricultural production. For efficient irrigation management, the crop water use must be understood. Agricultural researchers have developed many ways to measure or estimate the crop water use, such as water balance, energy balance, and micrometeorological methods, as well as numerous empirical approaches.

2.1.1 The Water Balance

The water balance for a defined system is expressed as

$$SM = SM_i + Pr + I - R - D - ET \tag{2.1}$$

where SM is soil moisture, Pr is precipitation, I is irrigation, R is runoff, D is drainage, and ET is evapotranspiration. The equation can be arranged to express evapotranspiration (ET) in terms of the other components of the system.

$$ET = \Delta SM + Pr + I - R - D \tag{2.2}$$

The accuracy of this method depends upon the accuracy with which the components can be measured or estimated. Drainage across the root zone (D) cannot be measured easily under field conditions; therefore, the ET estimate should be made when flow into or out of the root zone across the lower boundary of the soil profile can be determined or assumed to be zero. Precipitation (Pr), irrigation (I), and surface runoff (R) can be measured if the defined area is reasonably small. A water balance for a watershed or basin may be inaccurate because effective rainfall and irrigation will not be uniform across the area.

The accuracy in the measurement of the temporal change in soil moisture (ΔSM) depends upon the method of measurement and the time period of the water balance. There are inherently large errors involved in gravimetric sampling due to the spatial variability of soils and soil

moisture in the field and the small volume of soil sampled. Therefore, gravimetric sampling should not be used to estimate ET on a short term basis (daily or weekly). Neutron probe measurement is more accurate than gravimetric because a larger volume of soil is sampled and because repeated measurement can be made in a single location. The greater accuracy of neutron probe measurement allows measurement of weekly ET rates using the water balance method. For measurement of daily ET rates, an accurate weighing lysimeter is necessary. A lysimeter can also be constructed to measure drainage of water below the root zone, allowing measurement of ET during periods when drainage may not equal zero. A good discussion of the design considerations and uses of lysimeters is given by Tanner (1967).

2.1.2 The Energy Balance

The net radiation at the earth's surface is the balance of all incoming and outgoing long- and short-wave radiation. Because of the large quantity of energy required to evaporate water (586 cal g^{-1} at 20°C), evaporation is a major part of the energy balance. The vertical energy balance at the earth's surface is

$$Rn = ET + H + G + M \qquad (2.3)$$

The net radiation (Rn) and soil heat flux (G) are easily measured and miscellaneous fluxes (M), such as storage of heat in the canopy and plant growth and metabolism, are usually small and can be neglected. The apportioning of energy to sensible (H) and latent (E) heat is described by the Bowen ratio (β) as

$$\beta = H/E = \gamma(h_h/h_v)\ [(T_z - T_o)/(e_z - e_o)] \qquad (2.4)$$

where γ is the psychrometric constant, h_h and h_v are transfer coefficients for heat and vapor, respectively, T_z and T_o the temperatures at height z and at the surface, respectively, and e_z and e_o are the vapor pressures at height z and at the surface, respectively. Assuming $(h_h/h_v) = 1$, one

can write 2.3 and 2.4 as

$$E = (Rn - G)/(1 + \beta) \qquad (2.5a)$$

$$H = \beta(Rn - G)/(1 + \beta) \qquad (2.5b)$$

The Bowen ratio can be very useful for calculating evaporative flux using the energy balance method. Measurements of the gradient of temperature (T) and vapor pressure (e) are not difficult to obtain. The assumption of similarity of the transfer coefficient of heat (h_h) and vapor (h_v) is essential and may not be valid in all situations. In addition, the Bowen method assumes a planar surface with uniform sources and sinks for vapor and heat across the entire surface. This assumption is of questionable validity, particularly over row crops. (Tanner, 1968).

2.1.3 Micrometeorological Methods

Many micrometeorological methods have been developed which describe the physical processes of vapor and heat fluxes. Eddy correlation, aerodynamic, and combination approaches have been used to calculate evapotranspiration. Tanner (1967 and 1968) discusses these methods in detail.

Eddy correlation is based on the principle that the instantaneous mass flux of vapor in the vertical direction is the product of the vertical wind (w) and the vapor concentration (e) (Tanner, 1968). Using this method, the latent heat flux (E) at height z is expressed as

$$E_z = (\lambda\rho\varepsilon/P)\ [(\bar{e}\,\bar{w}) + \overline{e'w'}] \qquad (2.6)$$

where λ is the latent heat of vaporization, ρ is the density of moist air, ε is the ratio of the molecular weights of water vapor and air, and P is the atmospheric pressure. The sensible heat flux (H) is described as

$$H_z = (\rho c_p)\ [(\bar{T}\ \bar{w}) + \overline{T'w'}] \qquad (2.7)$$

where c_p is the specific heat at a constant pressure. If the flux is measured at surface, then the vertical wind speed will be zero and $\bar{T}$ and

$\bar{e}$ need not be measured. The latent and sensible heat fluxes will be described by the products of the variation from the mean of the vapor pressure (e') and vertical wind speed (w') and the temperature (T') and the vertical wind speed (w'), respectively.

Aerodynamic approaches describe vapor and heat fluxes as a function of vapor concentration (e) and temperature (T) gradients in the vertical direction. The flux from the surface to height z is expressed as

$$E_z = -(\lambda\rho\varepsilon/P)\ K_v\ (\partial e/\partial z)\ [=]\ \text{cal cm}^{-2}\ \text{sec}^{-1} \tag{2.8}$$

for vapor, where K_v is the eddy diffusivity for vapor, and

$$H_z = -\rho c_p K_h (\partial T/\partial z)\ [=]\ \text{cal cm}^{-2}\ \text{sec}^{-1} \tag{2.9}$$

for heat, where K_h is the eddy diffusivity for heat. The eddy diffusivities, K_v and K_h, express turbulent mixing in the profile and are strongly affected by windspeed.

A combination of the energy balance and aerodynamic formulas was first described by Penman (1948). Potential evaporative flux (PET) can be calculated as

$$\text{PET} = [s/(s + \gamma)]\ \{(Rn - G) + [(\rho c_p/s)h(e_z^* - e_z)]\} \tag{2.10}$$

where s is the slope of the saturation vapor curve and γ is the psychrometric constant. PET is the evapotranspiration of a short, green, well-watered crop under the prevailing climatic conditions. Priestley and Taylor (1972) described that under saturated conditions, $(e_z^* - e_z)$ would go to zero and equation (2.10) would simplify to

$$\text{PET} = \alpha[s/(s + \gamma)]\ [Rn - G] \tag{2.11}$$

van Bavel (1966) derived the following expression to eliminate the empiricism at a wind function described by Penman (1948).

$$\text{PET} = \frac{s/\gamma\ (Rn-G) + \lambda B_v d_a}{(s/\gamma) + 1}\ \text{cal cm}^{-2}\ \text{min}^{-1} \tag{2.12}$$

where λ is the latent heat of vaporization and d_a is the vapor pressure

deficit. The transfer coefficient, B_v, is described

$$B_v = \frac{\rho \varepsilon k^2}{P} \frac{u_a}{[\ln z_a/z_o]^2} \text{ g cm}^{-2} \text{ min}^{-1} \text{ mb}^{-1} \qquad (2.13)$$

where k is the von Karman constant, u_a is the wind speed at elevation z_a (cm min^{-1}), and z_o is the roughness coefficient (cm). The transfer coefficient, B_v, is based upon a standard wind profile under adiabatic conditions (van Bavel, 1966).

The potential evapotranspiration is the amount of water which would be lost from a short, green, full-cover crop, when water is not limiting. The actual evapotranspiration depends upon the crop and soil conditions. Denmead and Shaw, 1962; Jensen et al., 1970; Ritchie, 1972; Wright and Jensen, 1978; and many others have proposed empirical relationships between actual and potential evapotranspiration. Most of the proposed formulas are site-specific.

Micrometeorological methods describe the physical processes by which vapor moves from the plant surface into the atmosphere. The aerodynamic methods can only be used when the following assumptions are valid: 1) steady state conditions, 2) adiabatic conditions, 3) one-dimensional transport and 4) a homogeneous surface (Tanner, 1967). This limits the use of aerodynamic methods to calculation of short term (10 to 60 minutes) fluxes. Fetch requirements can be quite large depending on the dissimilarity of down-wind conditions and wind speed. The assumption of homogenity over row crops is questionable (Tanner, 1968). The eddy correlation methods are less dependent on surface conditions, but can also only be used for short time periods and have a stringent fetch requirement. Eddy correlation methods require accurate, fast-response sensors and instrumentation has limited the application of correlation principles in the past (Tanner, 1967).

2.1.4 Empirical Methods

Many have attempted to describe mathematically the relationship of

evapotranspiration and various environmental factors. The success of empirical methods for estimating evapotranspiration relies upon the correlation between climatic factors and potential evapotranspiration (PET). Radiation is highly correlated with PET, since solar radiation supplies the energy required for the vaporization of water. Temperature methods rely upon the correlation of temperature to radiation. Errors can arise because the cycles of radiation and temperature can be out of phase. Humidity methods have been proposed by Ostromecki, 1965; Papadakis, 1966; and others, but do not correlate well with actual data, unless they are linked to temperature or radiation formulas. Evaporation pans (Briggs & Shantz, 1916 and 1917; Pruitt and Jensen, 1955, Pruitt, 1960; Jensen et al. 1961) measure the energy available for evaporation, which can be related to crop water use under various conditions. The empirical relationships between pan evaporation and crop evapotranspiration are site-specific; local calibration, placement, and maintenance of the pans are crucial. (Jensen, 1973 and Tanner, 1968).

Radiation methods have been described by Makkink (1957), Jensen and Haise (1963), Turc (1961) and others. The Jensen-Haise equations, which have provided the basis for USDA-ARS Computerized Irrigation Scheduling Program, use a form of the Penman equation to calculate potential evapotranspiration. The actual evapotranspiration is related to the potential by use of a crop coefficient, K_{co}.

$$ET = K_{co}\ PET \tag{2.14}$$

Coefficients have been developed from experimental data and are described by Jensen (1968), Jensen, et al. (1970) and Wright and Jensen (1978).

Temperature methods by Thornthwaite (1948) and Blaney and Criddle (1950) were developed to calculate seasonal evapotranspiration from mean temperature data. Thronthwaite's method was developed in the eastern

U.S. and is generally not accurate if applied in dry, advective climates. The Blaney and Criddle formula follows the form

$$U = KF = \Sigma kf \tag{2.15}$$

where U is seasonal consumptive use, K and k, respectively, are seasonal and monthly crop and temperature coefficients and F and f, respectively, are seasonal and monthly temperature and daylight coefficients.

Data for these methods are readily available. Thornthwaite's method can be useful for comparison of consumptive use requirements for different areas (van Bavel, 1966). Blaney and Criddle's equations have been widely used in the western U.S. in engineering design problems (Jensen, 1973). van Wijk and de Vries (1954) discuss the difficulty of developing temperature based methods that can be used for more general application.

Christiansen (1968) and Christiansen and Hargreaves (1969) developed multiple regression equations which use pan evaporation or radiation data as well as temperature, wind, humidity and sunlight functions to estimate evapotranspiration. Jensen (1973) discusses these and other empirical methods of calculating evapotranspiration thoroughly. He points out that none of the currently available empirical formulas work well under all types of environmental conditions.

Ritchie (1972), Kanemasu et al. (1976), and Rosenthal et al. (1977) estimate evapotranspiration as the sum of evaporative and transpirative water loss from a field. Soil evaporation occurs in two phases--a constant-rate phase when the surface is wet, which will nearly match the potential evaporation at the surface, and a falling-rate which depends on the water transmitting properties of the soil and decreases with the square root of the number of days into the drying phase (Ritchie, 1972). Ritchie, (1972), Kanemasu, et al. (1976), and Rosenthal et al. (1977) relate transpiration to the leaf area index (ratio of green leaf surface area to soil surface area) of the crop. The work described in Chapter 3

of this text follows the evapotranspiration model described by Kanemasu et al. (1976) and Rosenthal et al. (1977).

2.1.5 Summary

Evapotranspiration can be measured or calculated using many methods and because ET is relatively conservative, reasonable values are obtained. Water balance methods are useful for calculating monthly or seasonal ET, using gravimetric sampling. With neutron probe determination of soil moisture, weekly ET can be calculated. In order to calculate daily ET by the water balance method, a weighing lysimeter is needed. Since lysimeters are not common, ET for only a limited number of crop management regimes can be obtained. Micrometeorological methods describe physical processes, and short term fluxes (less than one hour) can be measured; measurement and instrumentation requirements can be quite stringent.

To schedule irrigations in a regional program, calculation of daily ET from several different crops, on different soils, and under different cultural practices is necessary. Since actual measurement of evaporative flux is very time consuming, ET models, relating ET to various environmental factors, offers an attractive alternative. Kanemasu et al. (1976) have developed an empirical energy balance model which is based on actual processes as much as is possible. Potential evapotranspiration is calculated by the Priestley-Taylor formula as a function of net radiation and temperature. Actual evapotranspiration is calculated as the sum of evaporation from the soil surface and transpiration from the crop canopy. This model requires only solar radiation, maximum and minimum temperature, precipitation and leaf area index as daily inputs. The climatic data are easily available from weather stations. Leaf area index (LAI) can be measured in the field or calculated through leaf development models (Arkin, et al. 1976; Higgins et al. 1964). In the future, LAI values will be available from remotely sensed data (Pollock and Kanemasu, 1979). The simplicity of the model

input and calculations allows broad application of the evapotranspiration data for irrigation scheduling programs.

2.2 IRRIGATION SCHEDULING

The goal of irrigation scheduling is to apply water when the crop needs it, and in quantities that can be stored in the root zone. For effective scheduling, one must know the maximum amount of water in the soil profile which is available for uptake by the crop and the level to which the available water can be depleted without reducing the crop growth and yield. Knowledge of the soil moisture status, the rate of water use by the crop, crop development, and the acceptable level of soil moisture depletion throughout the season will allow effective and efficient scheduling of water applications.

Problems with irrigation scheduling arise when the moisture status is unknown. The soil moisture may be allowed to fall below the acceptable depletion level, or excessive water may be added which will result in surface runoff or drainage of moisture below the root zone. Both over- and under-watering are expensive and are wasteful of fuel, nutrients, and water resources.

2.2.1 Soil Moisture Monitoring

Several methods have been proposed to monitor soil moisture throughout the growing season of the crop. These methods vary from periodic sampling in a particular field to soil moisture balance methods using estimated evapotranspiration rates.

2.2.1.1 Probing Methods

Direct sampling in a field was the earliest method of soil moisture measurement. Early researchers (Isrealson, 1944) measured soil moisture gravimetrically. This method is still the most easily accessible to all, because it requires no specialized equipment--just a soil probe or auger, containers for the soil samples, an accurate scale, and a drying oven.

However, gravimetric measurement is time consuming, a 24 hour period for drying is required between sampling and analysis of data, several replications are needed due to the variability of soils and soil moisture in most fields, and measurement in a given location cannot be repeated.

A simpler method which is commonly used is the "feel" method (Merriam, 1960) in which the soil column is probed and the moisture at various depths is estimated by feeling the consistancy of the soil. This method is commonly used by agricultural consulting agents. The accuracy of the method depends upon the experience of the sampler and familiarity with a particular soil. The feel method suffers most of the limitations of the gravimetric methods, in addition to offering less precision, but it does provide direct and immediate information about the soil profile.

2.2.1.2 Soil Moisture Sensing Devices

Many soil moisture sensing devices have been proposed to reduce the labor and time necessary to determine soil moisture. Neutron probes are the favored method for use on research fields; electrical resistance blocks and tensiometers have been developed for use on farms.

Neutron attenuation provides a convenient, accurate measurement of soil moisture. (Holmes, 1950; Holmes and Jenkinson, 1959). Gear et al. (1977) proposed using the neutron probe to schedule irrigations. The neutron probe samples relatively large volumes of soil and allows for repeated sampling at a given location in a field. The average ET rate between two measurements can be determined by dividing the change in soil moisture by the number of days between measurement (assuming no irrigation, rainfall, or drainage below the root zone). Estimating the ET rate of a field enhances the accuracy and flexibility of irrigation scheduling. While neutron probes are desirable in many ways, they are quite expensive and require a licensed operator. Ownership and operation

is practical only for research or for a service agency which can use the equipment on several fields in an area.

Electrical resistance of the soil (Colman and Hendrix, 1949; and Bouyoucos and Mick, 1940) and the tension at which soil is held in the soil (Richards and Marsh, 1961) can be related to moisture in a soil. The use of these instruments require calibration in a particular soil for reliable interpretation of readings. The accuracy and reliability of these methods are less than with the neutron probe. The readings provide the approximate soil moisture, but cannot be used to estimate ET reliably.

When irrigation is scheduled using soil moisture measurement, there are often implicit assumptions made about crop water use rates. The efficiency of scheduling can be increased by considering water use rates more carefully.

2.2.1.3 Soil Moisture Balance Methods

Simple moisture balance methods have been proposed (van Bavel and Wilson, 1952; and Werner, 1978) to monitor soil moisture throughout the season. The balance, sometimes termed the "checkbook" method, requires measurement of soil moisture at the beginning of the season. Then, throughout the season, rain and irrigation are added and ET is substracted to calculate a periodic soil moisture balance. The accuracy of this method depends upon the initial soil moisture measurement, determination of effective rainfall and irrigation amounts, measurement of or absence of drainage of water below the root zone, and determination of evapotranspiration. The mean daily ET for a given area is quite conservative, i.e. is nearly the same from year to year, over a long period of time (about 30 days) but over shorter periods of time the variation from the mean can be large (Jensen and Wright, 1978). Moisture balance methods might result in crop stress during periods of unusually high ET, unless an

accurate determination of daily ET can be made.

2.2.2 Approaches to Irrigation Scheduling

The traditional approach to irrigation scheduling has been periodic watering, i.e. water is applied to each field at a particular time interval, no matter what the soil moisture status is. If water is plentiful, then applications are usually excessive during at least part of the season. If the water supply is limited and applied to a large area, then the crop will probably undergo drought stress at some point in the growing season.

Deficit, high-frequency irrigation has been proposed to limit the stress to the crop when working with limited water supplies. This method involves frequent, light irrigation applications which are less than the ET demand. Fereres et al. (1978) indicated that high-frequency irrigations do not reduce crop stress unless there is a soil moisture reserve which can be drawn upon during the growing season. The water demand of the crop must be met throughout the season, in order to avoid yield reduction. The allowable soil moisture depletion will change during the growing season, as the drought tolerance and ET demand of the crop change.

Limited irrigation practices, which allow mild stress to the crop during non-critical growth stages and ensure adequate moisture during specific sensitive growth stages, offer reduced water pumpage without decreases in yield (Stone et al. 1978).

2.2.3 Summary

Irrigation provides tremendous productivity and stability to agriculture in sub-humid to arid regions, but is very expensive through depletion of water and energy supplies. Wasteful irrigation practices need to be changed in order to protect these valuable resources and prolong irrigated production. Water savings can be realized, without reducing yield, through careful irrigation scheduling. Kanemasu et al. (1976) have developed

and tested an evapotranspiration model to predict daily ET in sub-humid to semi-arid climates, which is based on physical processes which occur in the field and supported with empirical observations, where necessary. Only maximum and minimum temperature, solar radiation, leaf area index, and rainfall (or irrigation) are required as daily inputs to the model. Use of this model (which is described in Chapter 3) will allow improved irrigation practices in Kansas, and can aid in the management of valuable water resources.

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CHAPTER III

MONITORING SOIL MOISTURE IN IRRIGATED CORN AND SORGHUM WITH A PROGRAMMABLE CALCULATOR

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ABSTRACT

Many models have been proposed to estimate evapotranspiration (ET) but few have been used by producers. We propose a model easily accessible to all potential users. Daily inputs--temperature, solar radiation, leaf area index, and rain or irrigation--are available from the National Weather Service or can be measured. Additionally, the model can be run on a programmable calculator, so access to computer facilities is not necessary. The model was tested on irrigated corn and sorghum in southwestern Kansas. Model estimates were compared with gravimetric measurements of soil moisture. The t-test of the mean difference (D) of estimated and observed soil moisture indicate a mean difference of zero at $P < .025$ for corn and $P < .20$ for sorghum. The model projected peak water use rates of 10.4 and 8.5 mm/day for corn and sorghum, respectively.

Introduction

Extensive irrigation development has provided tremendous productivity and stability to agricultural production in the High Plains region of the central United States. Increasing energy costs and depletion of stored water supplies make it desirable to use less water.

Researchers and scientists have focused on increasing water-use efficiency through more timely irrigation. Irrigators have been slow to accept devices to monitor soil moisture that use excessive time during the growing season. Monitoring water use on a regional basis is an attractive alternative. Several models have been proposed to estimate a crop's daily water use with climatic data (Jensen et al., 1970 and 1971; Kanemasu et al., 1976; Kincaid and Heerman, 1974; Ritchie, 1972; Rosenthal et al., 1977; and Tanner and Jury, 1976).

However, few of the models have been used by producers or their advisers. Potential users of evapotranspiration (ET) models include area or county extension specialists, groundwater or irrigation-management district personnel, and agricultural consultants. None may have access to computer facilities, and they may be reluctant to use models tested only on research farms. To provide potential users with a more accessible model, we simplified an ET model (Kanemasu et al., 1976) to run on a programmable calculator[1] and tested the model on ten farms in southwestern Kansas.

Methods and Materials

Data were collected in 1978 from fields in the Southwest Kansas Groundwater Management District (Fig. 1 and Table A1) to estimate daily water use by corn and sorghum crops. Initial data for each field (Table A3)

1/ We used a Hewlett-Packard-97 programmable calculator with printer and magnetic memory cards.

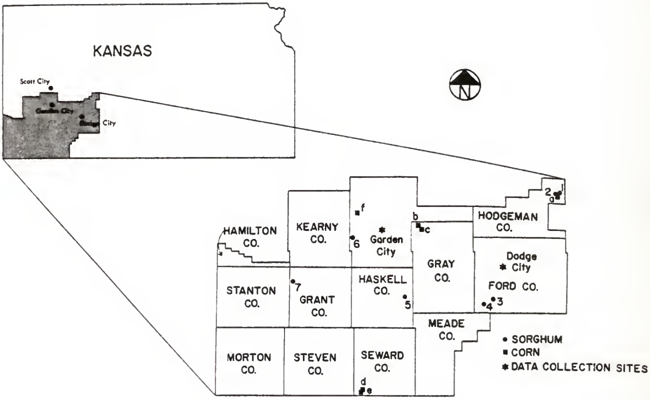

Fig. 3.1. Field locations in the Southwest Kansas Groundwater Management District. Climatic data from Dodge City were used as model inputs on fields 1, 2, 3, 4, a, d, and e. Temperatures from Garden City and solar radiation from Scott City were used as model inputs for fields 5, 6, 7, b, c, and f.

included soil moisture content, field capacity, and maximum available water of the soil, and soil evaporative constants c and U (Ritchie, 1972). We determined initial soil moisture gravimetrically by sampling from 0 to 15 cm and at 30, 60, 90, 120, and 150 cm. The average moisture content of two probe columns per field was the initial soil moisture. Other soil constants were taken from Jaafer et al. (1978). Gravimetric determination of soil moisture was repeated in mid to late July and mid to late August to check model estimates of soil moisture.

Daily inputs to the model are minimum and maximum temperature (°F), solar radiation (Langleys per day), leaf area index, rainfall (mm), and irrigation (mm). Temperature and/or solar radiation values were obtained from the National Weather Service in Dodge City, the U.S. Geological Survey in Scott City, and the Branch Agricultural Experiment Station in Garden City. Leaf area index (LAI) was measured weekly on each field assuming that

$$\mathrm{LAI} = \left[\sum_{i=1}^{n} .79(\ell_i \times w_i)\right] \left[\frac{\text{number of plants}}{\text{meter of row} \times \text{row width (m)}}\right] \tag{3.1}$$

where n is the number of leaves per plant and ℓ and w are the length and width, respectively, of each leaf. Values of LAI were interpolated linearly between measurements. Typical leaf area index curves for corn and sorghum are shown in Figures 2 and 3, respectively. Rainfall was measured at each field to the nearest 0.01 inch and irrigation water was measured by water flow meters to the nearest 0.001 acre-foot. Each irrigation application was assumed to be 70% and 85%, of pumped water for surface and sprinkler applications, respectively, except on two fields where open-ditch water flow and improper land leveling indicated 65% efficiency more appropriate.

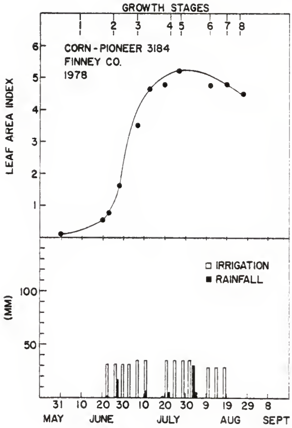

Fig. 3.2. Leaf area index, rainfall, irrigation, and growth stages after Hanway (1971) for a typical corn field (Field 6).

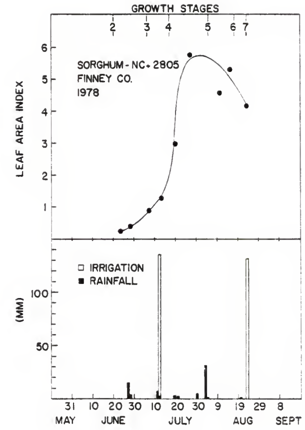

Fig. 3.3. Leaf area index, rainfall, irrigation, and growth stages after Vanderlip (1972) for a typical sorghum field (Field F).

Model

The model uses estimated values of daily water use to calculate a daily soil-moisture (SM) balance as

$$SM = SM_i + P_e + I - D - ET \tag{3.2}$$

where SM_i is initial soil moisture, P_e is effective precipitation, I is irrigation, D is drainage below the root zone, and ET is evapotranspiration. ET is a sum

$$ET = E_s + Tr + A \tag{3.3}$$

where E_s is evaporation from the soil surface, Tr is transpiration from the plant surface, and A is an advective component of transpiration, associated with high temperature.

Development of the ET model is detailed by Kanemasu et al. (1976 and 1978) and Rosenthal et al. (1977). Daily potential evapotranspiration (PET), defined as the energy-limited water loss from a well-watered, full-cover crop during nonadvective conditions, is calculated with Priestley and Taylor's (1972) equation

$$PET = \alpha[s/(s + \gamma)]Rn/59 \tag{3.4}$$

where α is a crop-and-climate-dependent constant equalling 1.35 and 1.28 for corn and sorghum, respectively, in Kansas; s is the slope of the saturation vapor curve; γ is the psychrometric constant: and Rn is the net radiation (Ly/day). The quantity $[s/(s + \gamma)]$ is primarily a function of temperature, calculated as

$$s/(s + \gamma) = 0.016\bar{T} - 5x10^{-6}\bar{T}^{-3} + 10^{-7}\bar{T}^{-4} + 0.4 \quad \text{with} \tag{3.5}$$

$$\bar{T} = (T_{max} + T_{min})/2 \tag{3.6}$$

where T_{max} and T_{min} are daily maximum and minimum temperatures (°C). Net radiation (Rn) is estimated from solar radiation for sorghum as

$$Rn = 0.73Rs - 51 \qquad LAI \leq 3 \text{ and} \tag{3.7a}$$

$$Rn = 0.84Rs - 132 \qquad LAI > 3 \tag{3.7b}$$

and for corn as

$$Rn = 0.86Rs - 103.9 \qquad LAI \leq 3 \qquad (3.7c)$$

$$Rn = 0.848Rs - 144.5 \qquad LAI > 3 \text{ and} \qquad (3.7d)$$

$$Rn = 0.766Rs - 99.9 \qquad LAI \leq 3 \text{ and } GDD > 1690 \qquad (3.7e)$$

where Rs is solar radiation (Ly/day), LAI is leaf area index, and GDD is growing degree days (Kanemasu et al., 1978).

Effective rainfall (P_e) is difficult to calculate because it depends on many interrelated topographic, soil, and management factors, and because infiltration at the soil surface is difficult to measure. We assume that runoff from most irrigated fields will be minimal for light precipitation (Pr) and use

$$P_e = [(Pr/25.4)^{.75}]25.4 \qquad \text{for } Pr \geq 25.4 \text{ mm} \qquad (3.8a)$$

$$P_e = Pr \qquad \text{for } Pr < 25.4 \text{ mm} \qquad (3.8b)$$

Evaporation from the soil surface occurs in two phases--a constant rate and a falling rate (Ritchie, 1972). The constant-rate phase is energy dependent and occurs when the soil surface is wet. The fraction of energy that reaches the soil surface (τ) depends on shading of the surface by crop cover; it is calculated as

$$\tau = \exp(-.39LAI) \qquad (3.9)$$

for both corn and sorghum. We calculate evaporation during the constant rate phase (E_1) as

$$E_1 = \tau[s/(s + \gamma)]Rn/59 \ [=] \text{ mm/day} \qquad (3.10a)$$

Evaporation during the falling-rate phase (E_2) depends on the soil's transmitting properties (c) and is calculated as

$$E_2 = [ct^{.5} - c(t-1)^{.5}] \ [=] \text{ mm/day} \qquad (3.10b)$$

where t is the number of days into the falling-rate phase. When the surface is wetted, water evaporates at a constant, energy-dependent rate until a threshold value (U) is reached, then the falling-rate phase begins. The values of c and U (Table A3) depend on the soil's textural and structural

properties. Jaafer et al. (1978) determined c and U values for several Kansas soils.

The program starts using (3.10b) to calculate evaporation and continues in the falling-rate phase until a rain or irrigation exceeds 6 mm; then a new evaporative cycle starts. Evaporation cannot exceed the energy limit on a given day; therefore, if E_2 is calculated and exceeds E_1, E_1 is used as the evaporation for that day.

For LAI < 3, transpiration (Tr) is calculated as

$$Tr = \alpha_v(1-\tau)[s/(s + \gamma)]Rn/59 \; [=] \; \text{mm/day} \tag{3.11a}$$

where α_v = 1.51 and 1.41 for corn and sorghum, respectively. For LAI $\geq$ 3, we use

$$Tr = (\alpha - \tau)[s/(s + \gamma)]Rn/59 \; [=] \; \text{mm/day} \tag{3.11b}$$

An advective component of transpiration is associated with high temperature. For 33°C < T_{max} < 36°C, we calculate advection (A) as

$$A = 0.1(T_{max} - 33°)Tr \tag{3.12a}$$

The upper limit of the advective component is 0.3 times the nonadvective transpiration. Therefore, for T_{max} > 36°C, we calculate

$$A = 0.3Tr \tag{3.12b}$$

The daily soil moisture is never allowed to exceed field capacity (FC). If soil moisture (SM) exceeds field capacity, then drainage (D) is set equal to the difference between the two, and soil moisture is set equal to field capacity. The depletion is calculated as

$$\%Dep = (FC - SM)/AW_{max} \tag{3.13}$$

Results and Discussion

Figures 4 and 5 show representative daily water use for corn and sorghum averaged over weekly periods. The highest average evapotranspiration rate predicted for our fields were 10.4 and 8.5 mm/day, respectively, for corn and sorghum. If water supply is limited, then sorghum might be a more suitable crop than corn, because it requires less water.

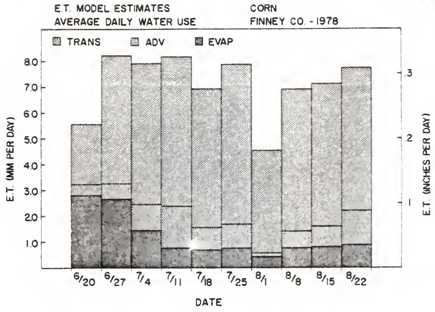

Fig. 3.4. Model estimates of average daily water use by corn, on a typical field (Field 6).

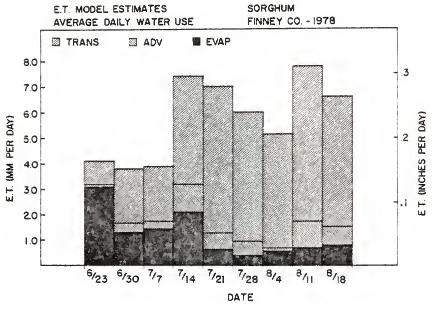

Fig. 3.5. Model estimates of average daily water use by sorghum, on a typical field (Field F).

Figures 6 and 7 show the relationship between soil moisture measured gravimetrically (y) and predicted soil moisture (x) for corn and sorghum, respectively. The regression line for our corn data is expressed

$$y = .79x + 108.75 \tag{3.14}$$

with $r^2 = .85$. Using the t-test of the mean difference (D), we calculate t (t_c) to equal 2.50. We can accept the null hypothesis that the mean difference is zero at $P < .025$ with $t_{.975(11)} = 2.593$. The regression line of our sorghum data is expressed

$$y = 1.04x + 5.87 \tag{3.15}$$

with $r^2 = .78$. We obtain a $t_c = .94$ and we accept the null hypothesis that the mean difference is zero at $P < .20$ with $t_{.80(9)} = 1.383$.

Tables 1 and 2 present water application and yield figures for our corn and sorghum fields. The goal of irrigation with limited water and fuel supplies may be to obtain the highest crop yield per unit of water applied, rather than the highest possible yield. Comparison of the water applied and yield of various fields indicates that some of the fields were over-watered. Particularly with the sorghum, there seems to be little relationship between the water applied to the fields and the yield, indicating that sorghum is a crop which allows "stretching" of limited water supplies, since moderate water application boosts yields dramatically and additional water may produce only a small yield increase. The two highest yielding corn fields received less water than two of the lower yielding fields. Excessive water application does not increase yield, and may even decrease the yield potential, through leaching of nitrogen and other nutrients from the root zone. The importance of timing of irrigation on corn is indicated by the lowest yielding field; the supply pump was under repair in late July, resulting in water stress to the crop during the late pollination and early grain-filling stages.

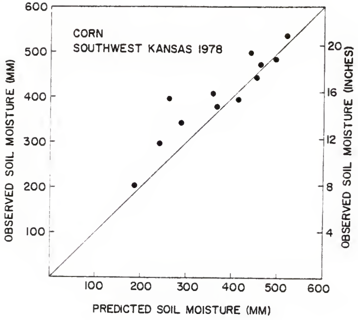

Fig. 3.6. Predicted and observed soil moisture of a 150 cm profile compared in irrigated corn.

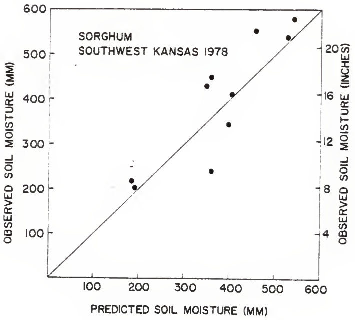

Fig. 3.7. Predicted and observed soil moisture of a 150 cm profile compared in irrigated sorghum.

Table 3.1. Irrigation (I), rainfall (R), and total water (Total) from June through August and grain yield (Yield) for corn.

Variety	I	R	Total	Yield
	mm			Kg/ha*
Pioneer 3195	571	75	646	7596†
Pioneer 3195	824	103	927	8297
Pr. Valley 76S	562	41	603	8650
Pr. Valley 76S	279	74	353	7155§
Hogmier 2649	352	35	387	4985
Pioneer 3184	518	78	596	9847
Acco 8951/7951	451	113	564	7497

*Yield reported at 0% moisture

†Harvested as silage, 48.6 metric ton/ha.

§Reported by cooperator.

Table 3.2. Irrigation (I), rainfall (R), and total water (Total) from June through August and grain yield (Yield) for sorghum.

Variety	I	R	Total	Yield
	mm			Kg/ha*
Pioneer 8311	471	107	578	6293
Acco GR 1028	232	51	283	5984
Pioneer 8501	355	60	415	5839
NK 2778	116	106	222	3378
NK 2778	235	106	341	4223
NC+ 2805†	369	91	460	4131

*Yield reported at 0% moisture.

†Seed production.

Conclusions

Irrigation requires large quantities of water and ample fuel supplies. In Kansas, more water is used for irrigation than for all other uses combined. In western Kansas, groundwater supplies are depleting at a rapid rate and fuel prices are rising, as worldwide competition for fuel supplies increases. If fuel or water supplies become limiting to irrigation the economy of western Kansas will suffer badly. Water requirements for irrigation can be reduced through more efficient irrigation system design and through careful irrigation scheduling.

We have developed and tested an evapotranspiration model which can be used for an irrigation scheduling program. The daily inputs--maximum and minimum temperature, solar radiation, leaf area index, irrigation and rainfall--are available from weather stations or can be measured on a particular field. The model satisfactorily estimated daily water use of corn and sorghum crops on ten irrigated farms in southwestern Kansas under several different irrigation management schemes. Predictive use of the model on an area-wide basis could provide irrigators with average daily water use of various crops, allowing more effective applications of water. Improved irrigation practices will prolong the use of water and fuel resources, protecting irrigated agriculture in southwestern Kansas.

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GLOSSARY

GLOSSARY

Symbol	Explanation	Units
A	Advective component of energy balance	mm day^{-1}
D	Drainage from the 150 cm profile	mm day^{-1}
E	Latent heat flux	cal cm^{-2} min^{-1}
E_s	Evaporation from the soil surface	mm day^{-1}
ET	Evapotranspiration	mm day^{-1}
G	Soil heat flux	cal cm^{-2} min^{-1}
H	Sensible heat flux	cal cm^{-2} min^{-1}
I	Irrigation	mm
$K_{h,v}$	Eddy diffusivities for heat and vapor	cm^2 sec^{-1}
LAI	Leaf area index	dimensionless
M	Miscellaneous fluxes	cal cm^{-2} min^{-1}
P	Air pressure	mb
Pr	Precipitation	mm
P_e	Effective precipitation	mm
PET	Potential evapotranspiration	mm day^{-1}
R	Runoff	mm
Rn	Net radiation	Ly day^{-1}
Rs	Solar radiation	Ly day^{-1}
SM	Soil moisture	mm
T	Temperature	°C
Tr	Transpiration	mm day^{-1}
c_p	Specific heat at constant pressure	0.24 cal g^{-1} $°C^{-1}$
e	Vapor pressure	mb
e*	Saturated vapor pressure	mb
$h_{h,v}$	Transfer coefficient for heat and vapor	cm sec^{-1}
k	von Karman constant	0.41
s	Slope of the saturation vapor curve	mb $°C^{-1}$

u	Horizontal wind speed	cm sec^{-1}, m day^{-1}
w	Vertical wind speed	cm sec^{-1}, m day^{-1}
β	Bowen ratio	dimensionless
γ	Psychrometric constant	mb $°C^{-1}$
ε	Ratio of molecular weights of water vapor and air	dimensionless
λ	Latent heat of vaporization	cal g^{-1}
ρ	Density of moist air	g cm^{-3}

Subscripts

i	Initial value
o	At the survace
z	At height z

Others

—	Indicates averaging or mean value
'	Prime indicates departure from the mean value
Δ	Increment
[=]	Indicates the units of a value

APPENDIX A

FIELD DATA

Table A1. Identification of Demonstration Project Fields

Field No.	Location	Cooperator	Irrigation Type	Soil Type
Corn				
1	SE¼, Sec. 34-21-21, Hodgeman Co.	Charles Lyman	Furrow	Roxbury silt loam
2	SW¼, Sec. 4-22-21, Hodgeman Co.	Tom Waterhouse, Jr.	Furrow	Roxbury silt loam-bench leveled
3	E½, SE¼, Sec. 4-29-25, Ford Co.	George Harshberger	Furrow	Harney silt loam
4	NE¼, Sec. 15-29-26, Ford Co.	Larry Sturgeon	Sprinkler	Harney silt loam
5	NE¼, Sec. 33-28-31, Haskell Co.	Herschell Webber	Sprikler	Richfield silt loam
6	NE¼, Sec. 6-25-34, Finney Co.	Dean Gigot	Sprinkler	Tivoli-Vona loamy fine sand
7	Partial, Sec. 31-27-38, Grant Co.	Ira Koop	Furrow	Ulysses silt loam
Sorghum				
A	SW¼, Sec. 4-22-21, Hodgeman Co.	Tom Waterhouse, Jr.	Furrow	Roxbury silt loam-bench leveled
B	NE¼, Sec. 9-24-30, Gray Co.	Wesley Werner	Sprinkler	Richfield-Spearville Complex (silt loam-silty clay loam)
C	SE¼, Sec. 15-24-30, Gray Co.	Wesley Werner	Sprinkler	Richfield-Spearville Complex (silt loam-silty clay loam)
D	Partial, Sec. 3-35-34, Seward Co.	Stan Boles	Sprinkler	Variable loamy fine sand
E	Partial, Sec. 3-35-34, Seward Co.	Stan Boles	Furrow	Dalhart fine sandy loam
F	SE¼, Sec. 21-23-24, Finney Co.	Bill Turrentine	Furrow	Ulysses and Richfield silt loam

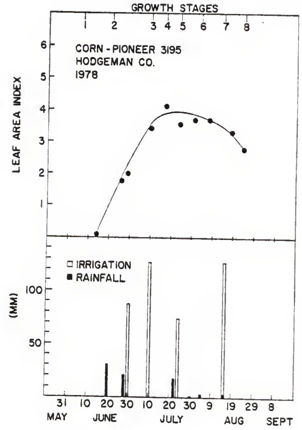

Fig. A.1. Leaf area index, rainfall, irrigation, and growth stages for Field 1.

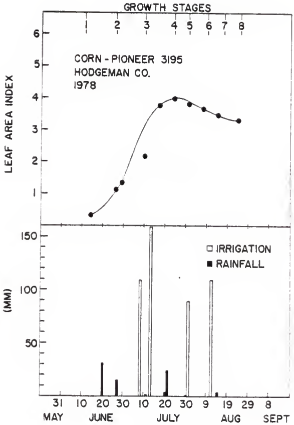

Fig. A.2. Leaf area index, rainfall, irrigation, and stages for Field 2.

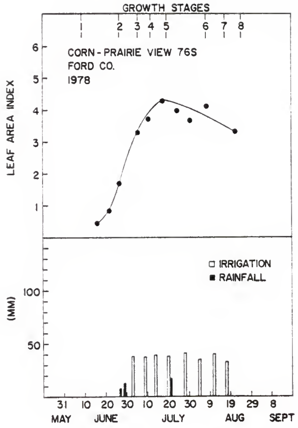

Fig. A.3. Leaf area index, rainfall, irrigation, and growth stages for Field 3.

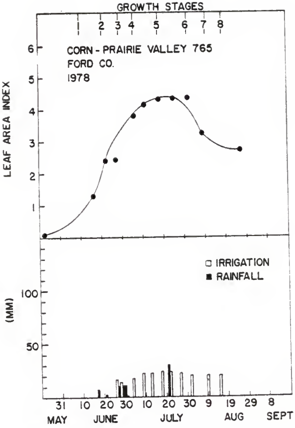

Fig. A.4. Leaf area index, rainfall, irrigation, and growth stages for Field 4.

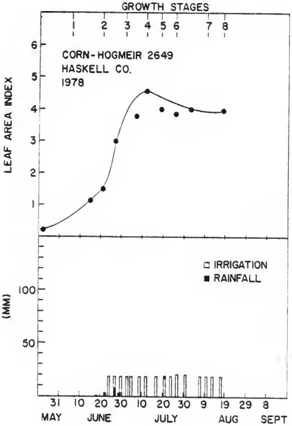

Fig. A.5. Leaf area index, rainfall, irrigation, and growth stages for Field 5.

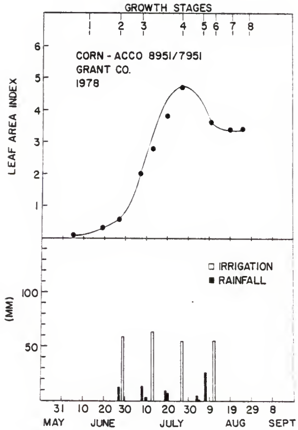

Fig. A.6. Leaf area index, rainfall, irrigation, and growth stages for Field 7.

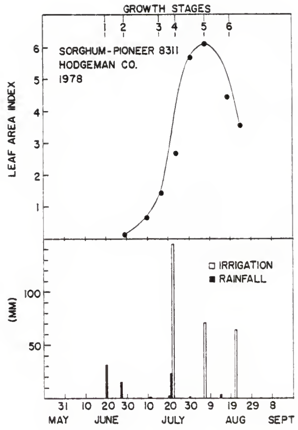

Fig. A.7. Leaf area index, rainfall, irrigation, and growth stages for Field A.

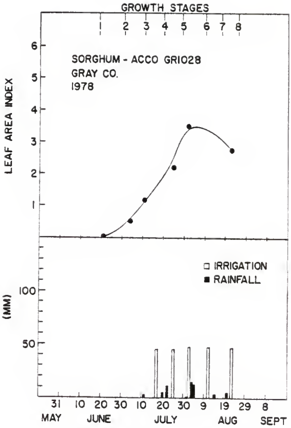

Fig. A.8. Leaf area index, rainfall, irrigation, and growth stages for Field B.

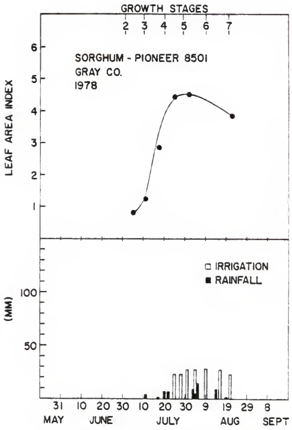

Fig. A.9. Leaf area index, rainfall, irrigation, and growth stages for Field C.

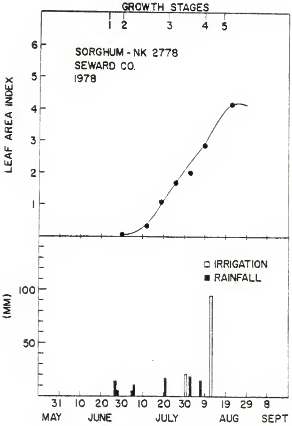

Fig. A.10. Leaf area index, rainfall, irrigation, and growth stages for Field D.

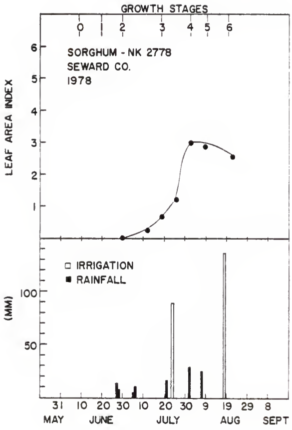

Fig. A.11. Leaf area index, rainfall, irrigation, and growth stages for Field E.

Table A2. Pumping Test Data from Irrigation Demonstration Fields[1/]

County	Field	Date	Aquifer	Static Water-Level	Sat. Thick-ness	Drawdown after 24 hrs.	Rate	Specific Capacity	Pumping Head	Fuel Consump. /A.F.	Fuel Consump. /A.F./ lift
				ft	ft	ft	gpm	gpm/ft D.D.	ft.		
Hodgeman	1	7/1-2	Alluvium	42.6	57	9.5	600	63	62	206 KWH	3.3 KWH
"	1	7/1-2	"	43.7	46	23.3	430	18	77	194 KWH	2.5 KWH
"	2,A	7/8	"	41.8	67	28	740	26	74	162 KWH	2.2 KWH
Gray	C	4/28	Ogallala	122	103	53	995	19	360	618 KWH	1.7 KWH
Finney	F	7/5	Ogallala	150	187	-	490	-	-	6800 ft^3	-
"	6	7/15	"	80	314	27	960	36	292	7900 ft^3	27 ft^3
Grant	7	6/27	"	211	269	40	1230	31	267	7760 ft^3	29 ft^3
Haskell	5	6/21-28	"	204	235	27	1260	47	346	8200 ft^3	24 ft^3
Ford	3	6/23-27	"	148	97	48	1110	23	-		-
"	4	6/23-24	"	90	130	14	620	44	298	10460 ft^3	35 ft^3

1/ Compiled by E. D. Jenkins, Hydrologist, Southwest Kansas, Groundwater Management District

Table A3. Initialization data for ET model

Field	$SM_{i\ 90}$	$SM_{i\ 150}$	$AW_{max\ 90}$	$AW_{max\ 150}$	FC_{90}	FC_{150}	c	U
Corn								
	mm						$mm/day^{1/2}$	mm
1	292	482	160	267	326	544	3.37	18.7
2	264	470	160	267	326	544	3.37	18.7
3	318	498	192	320	336	560	3.53	12.6
4	265	460	192	320	336	560	3.53	12.6
5	224	391	173	285	316	520	3.53	10.9
6	112	196	81	132	136	223	2.06	7.0
7	276	464	192	320	336	560	3.53	12.6
Sorghum								
A	293	485	160	267	326	544	3.37	18.7
B	328	534	192	320	336	560	3.53	12.6
C	270	404	192	320	336	560	3.53	12.6
D	126	224	81	132	136	223	2.06	7.0
E	190	332	136	223	232	385	2.41	9.0
F	257	437	192	320	336	560	3.53	12.6

APPENDIX B

LISTING OF THE MODEL AND RESULTS

GLOSSARY OF THE VARIABLE NAMES

```
C==============================================================================
C               EVAPOTRANSPIRATION MODELS FOR CORN AND SORGHUM
C==============================================================================
C                        ------VARIABLE DEFINITION------
C
C*    ADADV(26) -  AVERAGE DAILY ADVECTION FOR EACH WEEK
C*    ADET(26) -  AVERAGE DAILY EVAPOTRANSPIRATION FOR EACH WEEK
C*    ADEVAP(26) -  AVERAGE DAILY EVAPORATION FOR EACH WEEK
C*    ADPET(26) -  AVERAGE DAILY POTENTIAL EVAPOTRANSPIRATION FOR EACH WEEK
C*    ADTNS(26) -  AVERAGE DAILY TRANSPIRATION FOR EACH WEEK
C*    ADV      -  ADVECTIVE COMPONENT OF TRANSPIRATION
C*    AWC150   -  INPUT. MAXIMUM AVAILABLE WATER CAPACITY IN THE 150 CM PROFILE
C*                (MM)
C*    BEGWK(26,2) -  CONTAINS THE BEGINNING DATE (MO, DAY) OF EACH OF THE WEEKS
C*                   INCLUDED ON THE SUMMARY PAGE
C*    C        -  INPUT. SOIL TRANSMISSIBILITY CONSTANT (MM/DAY)
C*    CGDD     -  INPUT. CUMULATIVE GROWING DEGREE DAYS SINCE EMERGENCE OF THE
C*                CROP
C*    CRDFMT   -  INPUT. IDENTIFIES FORMAT OF DAILY DATA CARDS
C*    CTMAX    -  MAXIMUM TEMPERATURE (DEGREES CENTIGRADE)
C*    CTMIN    -  MINIMUM TEMPERATURE (DEGREES CENTIGRADE)
C*    D        -  CONTROL FOR DAILY LOOP
C*    DEP90    -  DEPLETION OF AVAILABLE WATER FROM 90 CM PROFILE
C*    DEP150   -  DEPLETION OF AVAILABLE WATER FROM 150 CM PROFILE
C*    DRN      -  DRAINAGE BELOW THE ROOT ZONE
C*    ENDWK(26,2) -  CONTAINS THE ENDING DATE (MO.DAY) OF EACH OF THE WEEKS
C*                   INCLUDED ON THE SUMMARY PAGE
C*    ET       -  EVAPOTRANSPIRATION
C*    EVAP     -  EVAPORATION FROM THE SOIL SURFACE
C*    EVAPC    -  CONSTANT RATE EVAPORATION
C*    EVAPF    -  FALLING RATE EVAPORATION
C*    FC150    -  INPUT. FIELD CAPACITY OF 150 CM PROFILE (MM)
C*    GDD      -  DAILY GROWING DEGREE DAYS
C*    IRR      -  DAILY INPUT. IRRIGATION (MM PER UNIT AREA)
C*    LAI      -  DAILY INPUT. LEAF AREA INDEX
C*    NODECK   -  INPUT. NUMBER OF FIELDS TO BE RUN
C*    PET      -  POTENTIAL EVAPOTRANSPIRATION
C*    PREC     -  EFFECTIVE PRECIPITATION
C*    RAIN     -  DAILY INPUT. RAINFALL (MM)
C*    RN       -  NET RADIATION
C*    RNOF     -  RUNOFF
C*    SM90     -  SOIL MOISTURE IN 90 CM PROFILE
C*    SM150    -  SOIL MOISTURE IN 150 CM PROFILE
C*    SMI90    -  INPUT. INITIAL SOIL MOISTURE IN THE 90 CM PROFILE (MM)
C*    SMI150   -  INPUT. INITIAL SOIL MOISTURE IN THE 150 CM PROFILE (MM)
C*    SR       -  DAILY INPUT. SOLAR RADIATION (LANGLEYS/DAY)
C*    SUMEV    -  SUMATION OF DAILY SOIL EVAPORATION, SET AT ZERO AT THE
C*                BEGINNING OF EACH EVAPORATIVE CYCLE
C*    T        -  NUMBER OF DAYS INTO FALLING RATE PHASE OF EVAPORATION
C*    TADV     -  SEASONAL TOTAL ADVECTION
C*    TAU      -  FRACTION OF NET RADIATION WHICH REACHES THE SOIL SURFACE
C*    TDRN     -  SEASONAL TOTAL DRAINAGE BELOW THE ROOT ZONE
C*    TEVAP    -  SEASONAL TOTAL EVAPORATION
C*    TITLE    -  INPUT. HOLDS CHARACTER STRING TITLE FOR EACH FIELD
```

```
C*     TMAX    -  DAILY INPUT. MAXIMUM TEMPERATURE (DEGREES FAHRENHEIT)
C*     TMIN    -  DAILY INPUT. MINIMUM TEMPERATURE (DEGREES FAHRENHEIT)
C*     TMN     -  MINIMUM TEMPERATURE USED FOR GROWING DEGREE DAY CALCULATION
C*     TMX     -  MAXIMUM TEMPERATURE USED FOR GROWING DEGREE DAY CALCULATION
C*     TPET    -  SEASONAL TOTAL POTENTIAL EVAPOTRANSPIRATION
C*     TRANSP  -  TRANSPIRATION FROM THE PLANT
C*     TRNOF   -  SEASONAL TOTAL RUNOFF
C*     TTET    -  SEASONAL TOTAL EVAPOTRANSPIRATION
C*     TTRNSP  -  SEASONAL TOTAL TRANSPIRATION
C*     U       -  INPUT. THRESHHOLD VALUE AT WHICH WE INITIATE THE FALLING RATE
C*                PHASE OF EVAPORATION
C*     W       -  CONTROL FOR WEEKLY LOOP
C*     WADV    -  WEEKLY TOTAL ADVECTION
C*     WEEKS   -  COUNTS THE NUMBER OF WEEKS IN GROWING SEASON
C*     WET     -  WEEKLY TOTAL EVAPOTRANSPIRATION
C*     WEVAP   -  WEEKLY TOTAL EVAPORATION
C*     WPET    -  WEEKLY TOTAL POTENTIAL EVAPOTRANSPIRATION
C*     WTNS    -  WEEKLY TOTAL TRANSPIRATION
C*     WTR     -  DAILY SUM OF IRRIGATION AND RAINFALL
```

LISTING OF THE CORN EVAPOTRANSPIRATION MODEL

```
    C=============================================================================
    C                          EVAPUTRANSPIRATION OF CURN
    C=============================================================================
    C
1         INTEGER  W      ,D       ,CRDFMT(20)       ,MD      ,DY      ,YR       ,
         *WEEKS   ,BEGWK(26,21/52*0/       ,ENDWK(26,21/52*0/,DECK ,
         *NODECK
2         REAL     TPET    ,TTET    ,CIMAX   ,CIMIN   ,SUMEV   ,EVAPC   ,EVAPF    ,
         *SM90    ,OEP90   ,TAU     ,TIRNSP  ,(ADV    ,TEVAP   ,TDRN    ,IRNOF    ,
         *OEP150  ,TMAX    ,TMIN    ,SR      ,LAI     ,RN      ,IRR     ,TRANSP   ,
         *ADV     ,EVAP    ,E(      ,PET     ,DRN     ,RNOF    ,CGDD    ,PREC     ,
         *WTR     ,TMX     ,TMN     ,SMI90   ,FC90    ,AWC90   ,SMI15D  ,FC150    ,
         *AWC150  ,C       ,U       ,T(TLE(2D)        ,WPET             ,T        ,
         *WTNS    ,WAOV    ,WEVAP   ,WET     ,RAIN    ,SM150   ,
         *ADTNS(26)/26*0./          ,ADADV(26)/26*D./          ,ADEVAP(26)/26*0./,
         *ADPET(26)/26*0./          ,ADET(26)/26*0./
    C
    C*----------> (NUOECK IS THE NUMBER OF OECKS (FIELOS( TO BE RUN ( <------------*
    C
3         READ (5,511) NODECK
    C
    C*----------> ICRDFMT IS A FORMAT USED TO READ THE OATA CARDS    ( <------------*
    C
4         READ (5,50D) (CRDFMT(N),N=1,2D)
5         DO 9D1 OECK=1,NODECK
    C
    C*----------> (    READ THE TITLE FOR EACH FIELO                  ) <------------*
    C
6         REAO (5,501) (TITLE(M),M=1,20)
    C
    C*----------> (     REAO THE FIELD CONSTANTS                      ( <------------*
    C
7         READ (5,506) SMI90,FC90,AWC90,SM(150,FC150,AWC150,C,U
    C
    C*----------> (MUST INITIALIZE THE CUMULATIVE GROWING DEGREE      ( <------------*
    C*----------> (OAYS BETWEEN EMERGENCE AND FIRST DAY DAILY         ) <------------*
    C*----------> (          DATA.                                    ( <------------*
    C
8         READ (5,512) CGDD
    C
    C*----------> (              PRINT THE TITLE                      ( <------------*
    C
9       5 WRITE (6,5D2) TITLE
    C
    C*----------> (          INITIALIZE VARIABLES.                    ) <------------*
    C
10        SUMEV=U
11        T=0.
12        TADV=D.
13        TDRN=D.
14        TEVAP=D.
15        TDRN=0.
16        TPEI=D.
17        TRANSP=0.
18        TRNOF=0.
19        TTET=D.
20        TTRNSP=D.
```

```
      WEEKS=0
C
C*----------> (     PRINT THE HEADING FOR THE DAILY DATA        ) <------------*
C
      WRITE (6,503)
C
C*----------> (    PROCESS THE DATA IN WEEKLY AND DAILY LOOPS    ) <------------*
C
      DO 100 W=1,26
      WADV=0.
      WET=0.
      WEVAP=0.
      WPET=0.
      WINS=0.
      DO 99 D=1,7
      READ (5,CRDFMT) MO,DY,YR,TMAX,TMIN,SR,LAI,RAIN,IRR
C
C*----------> (A BLANK CARD IS NEEDED TO SIGNAL THE END OF THE  ) <------------*
C*----------> (FIELD'S DAILY DATA.  WHEN THIS BLANK CARD IS READ) <------------*
C*----------> (ISR WILL BE 0, WHICH COULD NEVER HAPPEN OTHERWISE,) <------------*
C*----------> (THIS TEST WILL DROP THROUGH AND THE AVERAGE       ) <------------*
C*----------> (DAILY VALUES FOR THE LAST WEEK WILL BE CALCULATED) <------------*
C
      IF (SR.GT.0.0)GO TO 15
C
C*----------> (IF D IS EQUAL TO 1 WHEN THE BLANK CARD IS READ,  ) <------------*
C*----------> (IT WOULD MEAN THAT THE DATA ENDED ON A WEEK      ) <------------*
C*----------> (BOUNDARY, THEREFORE NO FURTHER CALCULATIONS NEED ) <------------*
C*----------> (TO BE MADE AND WE CAN BRANCH OUT OF THE LOOP.    ) <------------*
C
      IF(D.EQ.1)GO TO 900
      ADPET(W)=WPET/(D-1)
      ADINS(W)=WINS/(D-1)
      ADADV(W)=WADV/(D-1)
      ADEVAP(W)=WEVAP/(D-1)
      ADET(W)=WET/(D-1)
      GO TO 900
   15 TMX=TMAX
      TMN=TMIN
      IF(D.EQ.1)GO TO 20
      IF(D.EQ.7)GO TO 21
      GO TO 24
   20 WEEKS =WEEKS+1
      BEGWK(WEEKS,1)=MO
      BEGWK(WEEKS,2)=DY
      GO TO 24
   21 ENDWK(WEEKS,1)=MO
      ENDWK(WEEKS,2)=DY
C
C*----------> (     CALCULATE GROWING DEGREE DAYS.               ) <------------*
C
   24 IF(TMX.GT.86.)TMX=86.
      IF (TMN.LT.50.)TMN=50.
      GDD=(TMX+TMN)/2.-50.
      CGDD=CGDD+GDD
C
C*----------> (           CALCULATE NET RADIATION.               ) <------------*
C
      IF(LAI.GT.3.)RN=.85*SR-144.
      IF(LAI.LE.3..AND.CGDD.GT.1690.)RN=.77*SR-100.
```

```
      IF(LAI.LE.3..AND.CGDD.LE.1690.)RN=.86*SR-104.
C
C*----------> (CALL SUBROUTINE TO CONVERT TEMPERATURES FROM      ) <------------*
C*----------> (FARENHEIT TO CENTIGRADE.  THEN CALCULATE THE      ) <------------*
C*----------> (                 TEMPERATURE FUNCTION.            ) <------------*
C
   25 CALL CNTGR(TMAX,TMIN,CTMAX,CTMIN)
      TAVG=(CTMAX+CTMIN)/2.
      FTEMP=(.016*TAVG)-(5.E-6)*(TAVG**3)+(TAVG**4)/(1.E7)+.4
C
C*----------> (CALCULATE POTENTIAL EVAPOTRANSPIRATION,           ) <------------*
C*----------> (TRANSPIRATION, AND ADVECTION.                     ) <------------*
C
      PET=1.35*FTEMP*RN/59.
      TAU=EXP(-.39*LAI)
      IF(TAU.GT.1.)TAU=1.
      IF(LAI.GT.3.)TRANSP=(1.35-TAU)*FTEMP*RN/59.
      IF(LAI.LE.3.)TRANSP=1.51*(1-TAU)*FTEMP*RN/59.
      IF(TMAX.LE.91.)ADV=0.
      IF(91..LT.TMAX.AND.TMAX.LT.97.)ADV=.1*(TMAX-91.)*TRANSP*5./9.
      IF(TMAX.GE.97.)ADV=0.3*TRANSP
C
C*----------> (CALCULATE EFFECTIVE PRECIPITATION AND RUNOFF.     ) <------------*
C
   50 IF(RAIN.LE.25.4)PREC=RAIN
      IF(RAIN.GT.25.4)PREC=(RAIN/25.4)**.75*25.4
   60 RNOF=RAIN-PREC
      TRNOF=TRNOF+RNOF
      WTR=PREC+IRR
C
C*----------> (CALCULATE EVAPORATION FROM THE SOIL SURFACE.      ) <------------*
C
      EVAPC=TAU*FTEMP*RN/59.
      IF(PET.LE.0.)GO TO 62
      IF(WTR.GT.6.)GO TO 64
   61 IF(SUMEV.LT.U)GO TO 66
      T=T+1.
      EVAPF=C*(SQRT(T)-SQRT(T-1.))
      IF(EVAPF.GT.EVAPC)GO TO 66
      EVAP=EVAPF
      GO TO 70
   62 TRANSP=0.
      ADV=0.
      EVAP=0.
      IF(WTR.LE.6.)GO TO 70
      SUMEV=0.
      T=0.
      GO TO 70
   64 SUMEV=0.
      T=0.
   66 EVAP=EVAPC
   70 SUMEV=SUMEV+EVAP
C
C*----------> (CALCULATE THE SOIL MOISTURE BALANCE.              ) <------------*
C
      ET=TRANSP+EVAP+ADV
      SM90=SMI90-ET+WTR
      IF(SM90.GT.FC90)SM90=FC90
      DEP90=((FC90-SM90)/AWC90)*100
      SMI90=SM90
```

```
      SM150=SMI150-ET+WTR
      IF(SM150.LE.FC150)GO TO 75
      DRN=SM150-FC150
      TDRN=TDRN+DRN
      SM150=FC150
   75 DEP150=((FC150-SM150)/AWC150)*100
      SMI150=SM150
C
C*----------> (      PRINT THE DAILY VALUES                  ) <-----------*
C*----------> (WE CHOSE TO CONSIDER A 150 CM ROOT ZONE WHEN    ) <-----------*
C*----------> (PRINTING SOIL MOISTURE VALUES.  A 90 CM CAN BE  ) <-----------*
C*----------> (SELECTED IF IT SEEMS MORE APPROPRIATE.          ) <-----------*
C
   80 WRITE (6,507) MO,DY,TMAX,TMIN,SR,LAI,IRR,RAIN,PET,TRANSP,ADV,EVAP,
     *ET,SM150,DEP150
      TTRNSP=TTRNSP+TRANSP
      TADV=TADV+ADV
      TEVAP=TEVAP+EVAP
      TTET=TTET+ET
      TPET=TPET+PET
      WPET=WPET+PET
      WTNS=WTNS+TRANSP
      WADV=WADV+ADV
      WEVAP=WEVAP+EVAP
      WET=WET+ET
      NODY=DY
      NDMO=MO
   99 CONTINUE
      ADPET(W)=WPET/7
      ADTNS(W)=WTNS/7
      ADADV(W)=WADV/7
      ADEVAP(W)=WEVAP/7
      ADET(W)=WET/7
  100 CONTINUE
  900 ENDWK(WEEKS,1)=NDMO
      ENDWK(WEEKS,2)=NDDY
C
C*----------> (      PRINT THE SUMMARY OF SEASON TOTALS        ) <-----------*
C
      WRITE (6,510) (TITLE(M),M=1,20)
      WRITE (6,505) TTRNSP,TADV,TEVAP,TTET,TPET,TDRN,TRNOF
C
C*----------> (      PRINT THE AVERAGE DAILY VALUES FOR EACH WEEK) <-----------*
C
      WRITE (6,504)
      IF(ENDWK(WEEKS,1).NE.0)GO TO 101
      ENDWK(WEEKS,1)=MO
      ENDWK(WEEKS,2)=DY
  101 DO 103 I=1,WEEKS
      WRITE (6,508) BEGWK(I,1),BEGWK(I,2),ENDWK(I,1),ENDWK(I,2),
     *ADPET(I),ADTNS(I),ADADV(I),ADEVAP(I),ADET(I)
  103 CONTINUE
  901 CONTINUE
      WRITE (6,509)
C
C*----------> (  ALL OF THE FORMATS, BOTH READ AND WRITE, WERE  ) <-----------*
C*----------> (  COLLECTED AND PUT HERE.                        ) <-----------*
C
  500 FORMAT(20A4)
  501 FORMAT(20A4)
```

```
502  FORMAT ('1',/,41X,20A4)
503  FORMAT     1/,10X,'MAX',7X,'MIN',7X,'SOLAR',63X,'SOIL',15X,'SM',
    *8X,'%DEPL',/,' MO DAY',3X,2('TEMP',6X),' RAD.',5X,'LAI',6X,'IRR',
    *7X,'PRECIP',4X,'PET',7X,'TRANS',5X,'ADV',6X,'EVAP',6X,'ET',7X,
    *'150',8X,'150',/,10X,'(F)',7X,'(F)',6X,'(LGY/D)',13X,'(MM)',
    *7X, '(MM)',
    *5X,'(MM)',2(6X,'(MM)'),5X,'(MM)',5X,'(MM)',6X,'(MM)',
    */,' ',132('-'))
504  FORMAT (////,55X,'AVERAGE DAILY VALUES',/,62X,' (MM)',/,
    */,37X,' MO/DAY-MO/DAY',6X,'PET',5X,'TRANS',5X,'ADV',5X,'EVAP',
    *6X,'ET',/,36X,61('-'))
505  FORMAT  (' ',50X,'SEASONAL TOTAL:', 7X,' MM H O',/,77X,' 2',/,
    *49X,' ',30('-'),/,
    *51X,'TRANSPIRATION  . . . . .', F7.1,/,51X,'ADVECTION  . . . . . . .',
    * F7.1,/,51X,'SOIL EVAPORATION . . .', F7.1,/,51X,
    *'ET . . . . . . . . . . .', F7.1,/,51X,'PET  . . . . . . . . . .',
    * F7.1,/,51X,'DRAINAGE . . . . . . . .', F7.1,/,51X,
    *'RUNOFF . . . . . . . . .',F7.1)
506  FORMAT (F5.0,F7.0,F7.0,F6.0,2F7.0,F6.0,F6.0)
507  FORMAT  1I2,I4,F8.0,F10.0,F11.0,F9.3,F9.1,F11.1,F9.2,F11.2,F9.2,
    *F9.2,F9.2,F10.0,F11.1)
508  FORMAT (38X,I2,'/',I2,' -',I2,'/',I2,F10.2,F10.2,F8.2,F9.2,F9.2)
509  FORMAT ('1')
510  FORMAT  ('1',4(/,'-'),41X,20A4,//)
511  FORMAT(20(I2,1X))
512  FORMAT (F4.0)
     STOP
     END

     SUBROUTINE CNTGR(TMAX,TMIN,CTMAX,CTMIN)
     CTMAX=(TMAX-32)*5/9
     CTMIN=(TMIN-32)*5/9
     RETURN
     END

$ENTRY
```

RESULTS FOR CORN FIELDS

GMO FIELO 3. CORN - PRAIRIE VALLEY 765. FORO CO. 1978.

MO	DAY	MAX TEMP (F)	MIN TEMP (F)	SOLAR RAO. (LGY/O)	LAI	IRR (MM)	PRECIP (MM)	PET (MM)	TRANS (MM)	AOV (MM)	SOIL EVAP (MM)	ET (MM)	SM 150 (MM)	%DEPL 150
6	16	101.	74.	726.	0.480	0.0	0.0	9.97	1.90	0.57	3.53	6.00	492.	21.3
6	17	90.	67.	713.	0.539	0.0	0.0	8.99	1.91	0.00	1.46	3.37	489.	22.3
6	18	82.	62.	585.	0.597	0.0	0.0	6.62	1.54	0.00	1.12	2.66	486.	23.1
6	19	95.	62.	459.	0.656	0.0	2.0	5.13	1.30	0.29	0.95	2.53	485.	23.3
6	20	78.	62.	535.	0.741	0.0	0.0	5.79	1.63	0.00	0.83	2.46	483.	24.1
6	21	79.	61.	234.	0.773	0.0	0.0	1.58	0.46	0.00	0.75	1.21	482.	24.4
6	22	96.	66.	704.	0.831	0.0	0.0	9.06	2.81	0.78	0.69	4.28	477.	25.8
6	23	99.	71.	721.	1.004	0.0	0.0	9.67	3.50	1.05	0.64	5.20	472.	27.4
6	24	101.	68.	713.	1.178	0.0	0.0	9.50	3.91	1.17	0.61	5.69	467.	29.2
6	25	108.	79.	667.	1.351	53.4	0.0	9.49	4.35	1.30	4.15	9.81	510.	15.6
6	26	98.	72.	680.	1.525	0.0	0.0	9.01	4.52	1.35	3.68	9.55	501.	18.6
6	27	93.	67.	346.	1.698	0.0	8.1	3.47	1.88	0.21	1.32	3.41	505.	17.1
6	28	97.	69.	700.	1.876	0.0	0.0	9.16	5.32	1.60	3.27	10.18	495.	20.3
6	29	97.	70.	461.	2.050	0.0	15.2	5.40	3.33	1.00	1.80	6.13	504.	17.4
6	30	96.	69.	475.	2.231	0.0	0.0	5.58	3.62	1.01	1.73	6.36	498.	19.4
7	1	97.	70.	686.	2.409	0.0	0.0	8.98	6.12	1.84	2.60	10.56	487.	22.7
7	2	100.	68.	720.	2.586	0.0	0.0	9.56	6.80	2.04	2.58	11.42	476.	26.3
7	3	103.	74.	723.	2.764	38.3	0.0	10.01	7.38	2.22	2.52	12.12	502.	18.1
7	4	102.	74.	724.	2.942	0.0	0.0	9.98	7.62	2.29	2.35	12.25	490.	21.9
7	5	105.	74.	658.	3.119	0.0	0.0	8.10	6.32	1.90	1.78	9.99	480.	25.1
7	6	105.	74.	643.	3.297	0.0	0.0	7.85	6.24	1.87	1.61	9.72	470.	28.1
7	7	92.	67.	594.	3.383	0.0	0.0	6.43	5.16	0.29	1.27	6.72	463.	30.2
7	8	109.	71.	568.	3.469	0.0	0.0	6.64	5.37	1.61	1.27	8.25	455.	32.8
7	9	91.	71.	649.	3.556	37.9	0.0	7.37	6.00	0.00	1.36	7.37	486.	23.2
7	10	87.	64.	479.	3.642	0.0	0.0	4.52	3.71	0.00	0.81	4.52	481.	24.6
7	11	104.	69.	599.	3.728	0.0	0.0	6.93	5.73	1.72	1.20	8.65	472.	27.3
7	12	105.	81.	654.	3.805	0.0	0.0	8.29	6.90	2.07	1.39	10.36	462.	30.6
7	13	97.	70.	259.	3.883	0.0	0.0	1.41	1.18	0.35	0.23	1.76	460.	31.1
7	14	105.	68.	656.	3.960	39.3	0.0	7.85	6.61	1.98	1.24	9.84	490.	21.9
7	15	100.	68.	704.	4.038	0.0	0.0	8.44	7.14	2.14	1.29	10.58	479.	25.2
7	16	99.	75.	502.	4.115	0.0	0.0	5.39	4.59	1.38	0.80	6.77	472.	27.3
7	17	103.	73.	674.	4.192	0.0	0.0	8.25	7.06	2.12	1.19	10.37	462.	30.6
7	18	104.	77.	643.	4.270	0.0	0.0	7.92	6.81	2.04	1.11	9.56	452.	33.7
7	19	101.	70.	449.	4.230	0.0	0.0	4.47	3.84	1.15	0.64	5.62	447.	35.5
7	20	100.	70.	384.	4.191	38.3	0.0	3.42	2.92	0.88	0.49	4.29	481.	24.8
7	21	101.	71.	565.	4.151	0.0	17.8	6.36	5.42	1.63	0.93	7.98	490.	21.8
7	22	83.	61.	652.	4.111	0.0	0.0	6.81	5.79	0.00	1.01	6.81	484.	23.9
7	23	82.	57.	585.	4.071	0.0	0.0	5.71	4.85	0.00	0.87	5.71	478.	25.7
7	24	93.	60.	666.	4.032	0.0	0.0	7.31	6.19	0.69	1.12	8.00	470.	28.2
7	25	100.	66.	709.	3.992	0.0	0.0	8.44	7.12	2.14	1.32	10.57	459.	31.5
7	26	99.	64.	710.	3.981	0.0	0.0	8.34	7.03	2.11	1.31	10.45	449.	34.7
7	27	94.	64.	706.	3.966	0.0	0.0	8.09	6.81	1.14	1.28	9.23	440.	37.6
7	28	100.	65.	716.	3.950	41.8	0.0	8.51	7.16	2.15	1.35	10.66	471.	27.9
7	29	97.	69.	692.	3.934	0.0	0.0	8.17	6.87	2.06	1.31	10.23	461.	31.1
7	30	89.	63.	550.	3.918	0.0	0.0	5.58	4.68	0.00	0.90	5.58	455.	32.8
7	31	97.	64.	669.	3.903	0.0	0.0	7.64	6.40	1.92	1.23	9.56	445.	35.8
8	1	95.	66.	475.	3.887	0.0	0.0	4.67	3.91	0.87	0.76	5.54	440.	37.6
8	2	90.	70.	576.	3.887	0.0	0.0	6.19	5.18	0.00	1.01	6.19	434.	39.5
8	3	72.	54.	322.	3.887	0.0	0.0	1.96	1.64	0.00	0.32	1.96	432.	40.1
8	4	67.	53.	205.	3.887	35.9	0.0	0.44	0.37	0.00	0.07	0.44	467.	29.0
8	5	81.	56.	591.	3.887	0.0	0.0	5.74	4.80	0.00	0.93	5.74	461.	30.8
8	6	89.	60.	695.	3.887	0.0	0.0	7.60	6.36	0.00	1.24	7.60	454.	33.2
8	7	92.	64.	458.	3.887	0.0	0.0	4.31	3.61	0.20	0.70	4.51	449.	34.6

8	8	87.	63.	591.	3.887	0.0	0.0	6.12	5.13	0.00	1.00	6.12	443.	36.5
8	9	86.	61.	638.	3.859	0.0	0.0	6.71	5.60	0.00	1.10	6.71	436.	38.6
8	10	95.	66.	633.	3.832	0.0	0.0	7.09	5.91	1.31	1.18	8.40	428.	41.2
8	11	101.	66.	658.	3.804	40.2	0.0	7.68	6.39	1.92	1.29	9.59	459.	31.7
8	12	105.	71.	758.	3.777	0.0	0.0	9.63	7.99	2.40	1.63	12.02	447.	35.4
8	13	101.	73.	659.	3.749	0.0	0.0	7.94	6.57	1.97	1.36	9.91	437.	38.5
8	14	95.	75.	392.	3.722	0.0	0.0	3.54	2.93	0.65	0.61	4.19	433.	35.8
8	15	88.	56.	677.	3.694	0.0	0.0	7.16	5.90	0.00	1.26	7.16	425.	42.1
8	16	101.	61.	630.	3.666	0.0	0.0	7.07	5.82	1.75	1.25	8.82	417.	44.8
8	17	106.	76.	659.	3.639	33.7	0.0	8.23	6.75	2.03	1.47	10.25	440.	37.5
8	18	86.	63.	647.	3.611	0.0	0.0	6.90	5.65	0.00	1.25	6.90	433.	39.7
8	19	83.	55.	591.	3.584	0.0	0.0	5.77	4.71	0.00	1.06	5.77	427.	41.5
8	20	90.	61.	482.	3.556	0.0	0.0	4.56	3.72	0.00	0.84	4.56	423.	42.9
8	21	98.	70.	614.	3.529	0.0	0.0	7.02	5.70	1.71	1.31	8.73	414.	45.6
8	22	99.	73.	587.	3.501	0.0	0.0	6.71	5.44	1.63	1.27	8.34	406.	48.2

GMD FIELD 3. CORN - PRAIRIE VALLEY 765. FORD CO. 1978.

SEASONAL TOTAL:	MM H_2O
TRANSPIRATION	333.9
ADVECTION	70.5
SOIL EVAPORATION . . .	89.8
ET	494.2
PET	464.2
DRAINAGE	0.0
RUNOFF	0.0

AVERAGE DAILY VALUES
(MM)

MO/DAY-MO/DAY	PET	TRANS	ADV	EVAP	ET
6/16 - 6/22	6.73	1.65	0.23	1.33	3.22
6/23 - 6/29	7.96	3.83	1.10	2.21	7.14
6/30 - 7/ 6	8.58	6.30	1.88	2.17	10.35
7/ 7 - 7/13	5.94	4.86	0.86	1.08	6.80
7/14 - 7/20	6.53	5.57	1.67	0.97	8.20
7/21 - 7/27	7.29	6.17	1.10	1.12	8.39
7/28 - 8/ 3	6.10	5.12	1.00	0.98	7.10
8/ 4 - 8/10	5.43	4.54	0.22	0.89	5.64
8/11 - 8/17	7.32	6.05	1.53	1.27	8.85
8/18 - 8/22	6.19	5.04	0.67	1.15	6.86

GMD FIELD 1. CORN - HODGEMAN CO. 1978.

SEASONAL TOTAL:	MM H_2O
TRANSPIRATION	316.8
ADVECTION	67.8
SOIL EVAPORATION . . .	84.2
ET	468.8
PET	405.0
DRAINAGE	42.5
RUNOFF	0.0

AVERAGE DAILY VALUES
(MM)

MO/DAY-MO/DAY	PET	TRANS	ADV	EVAP	ET
6/26 - 7/ 2	7.31	4.58	1.31	2.38	8.27
7/ 3 - 7/ 9	8.55	6.45	1.51	2.04	10.00
7/10 - 7/16	6.12	5.07	1.36	1.05	7.48
7/17 - 7/23	6.13	5.19	1.11	0.95	7.24
7/24 - 7/30	7.78	6.47	1.45	1.31	9.23
7/31 - 8/ 6	4.89	4.03	0.39	0.86	5.28
8/ 7 - 8/13	7.07	5.73	1.08	1.19	8.01
8/14 - 8/20	6.18	4.85	0.61	1.33	6.78
8/21 - 8/24	6.71	5.07	1.52	1.61	8.20

GMU FIELD 2. CORN - HOOGEMAN CO. 1978.

SEASONAL TOTAL:	MM H_2O
TRANSPIRATION	301.5
AOVECTION	63.2
SOIL EVAPORATION . . .	93.4
ET	458.0
PET	411.4
ORAINAGE	80.3
RUNOFF	0.0

AVERAGE DAILY VALUES
(MM)

MO/OAY-MO/OAY	PET	TRANS	AOV	EVAP	ET
6/26 - 7/ 2	7.31	3.38	0.97	3.05	7.40
7/ 3 - 7/ 9	8.68	5.02	1.13	2.26	8.41
7/10 - 7/16	6.60	4.90	1.32	1.61	7.84
7/17 - 7/23	6.13	5.12	1.09	1.01	7.22
7/24 - 7/30	7.78	6.51	1.46	1.27	9.24
7/31 - 8/ 6	5.11	4.24	0.40	0.87	5.51
8/ 7 - 8/13	7.07	5.78	1.09	1.29	8.16
8/14 - 8/20	6.17	4.58	0.62	1.19	6.79
8/21 - 8/24	6.88	5.50	1.65	1.38	8.53

GMD FIELD 4. CORN - FORD CO. 1978.

SEASONAL TOTAL:	MM H_2O
TRANSPIRATICN	365.4
ADVECTION	77.0
SOIL EVAPORATION . . .	86.4
ET	528.8
PET	460.6
DRAINAGE	0.0
RUNOFF	1.4

AVERAGE CAILY VALUES
(MM)

MO/DAY-MO/DAY	PET	IRAKS	ADV	EVAP	ET
6/16 - 6/22	6.74	3.71	0.53	2.40	6.63
6/23 - 6/29	7.96	5.50	1.59	1.84	8.92
6/30 - 7/ 6	8.07	6.45	1.92	1.62	9.99
7/ 7 - 7/13	5.94	5.07	0.90	0.87	6.84
7/14 - 7/20	6.53	5.63	1.69	0.90	8.22
7/21 - 7/27	7.29	6.31	1.12	0.98	8.42
7/28 - 8/ 3	6.10	5.28	1.03	0.82	7.13
8/ 4 - 8/10	5.43	4.60	0.22	0.83	5.65
8/11 - 8/17	7.31	6.07	1.53	1.24	8.85
8/18 - 8/22	6.19	5.03	0.67	1.16	6.85

GMD FIELD 5. CORN - HOGMEIR 2649. HASKELL CO. 1978.

SEASONAL TOTAL:	MM H_2O
TRANSPIRATION	343.9
ADVECTION	74.0
SOIL EVAPORATION . . .	74.6
ET	492.4
PET	442.8
DRAINAGE	0.0
RUNOFF	0.0

AVERAGE CAILY VALUES
(MM)

MO/DAY-MO/DAY	PET	TRANS	ADV	EVAP	ET
6/15 - 6/21	6.82	3.04	0.43	1.33	4.80
6/22 - 6/28	8.23	5.56	1.60	1.65	8.80
6/29 - 7/ 5	7.49	6.05	1.80	1.43	9.29
7/ 6 - 7/12	6.86	5.66	1.13	1.00	7.99
7/13 - 7/19	6.25	5.36	1.61	0.89	7.85
7/20 - 7/26	6.63	5.56	1.05	1.07	7.68
7/27 - 8/ 2	6.98	5.87	1.16	1.10	8.14
8/ 3 - 8/ 9	4.70	3.57	0.03	0.73	4.72
8/10 - 8/16	7.16	6.04	1.45	1.12	8.61
8/17 - 8/18	7.56	6.37	1.04	1.19	8.60

GMO FIELD 6. CORN - PIONEER 3184. FINNEY CO. 1978.

SEASONAL TOTAL:	MM H_2O
TRANSPIRATICN	326.8
ADVECTION	52.7
SOIL EVAPORATION . . .	78.6
ET	458.1
PET	420.7
DRAINAGE	81.4
RUNOFF	1.4

AVERAGE DAILY VALUES
(MM)

MO/DAY-MO/DAY	PET	TRANS	ADV	EVAP	ET
6/20 - 6/26	6.94	2.32	0.47	2.86	5.65
6/27 - 7/ 3	8.01	4.51	0.64	2.68	8.24
7/ 4 - 7/10	6.80	5.45	1.02	1.35	7.82
7/11 - 7/17	6.59	5.78	1.65	0.81	8.24
7/18 - 7/24	6.06	5.38	0.85	0.68	6.91
7/25 - 7/31	6.90	6.22	0.89	0.69	7.80
8/ 1 - 8/ 7	4.43	3.56	0.15	0.47	4.58
8/ 8 - 8/14	6.20	5.50	0.69	0.71	6.90
8/15 - 8/21	6.33	5.58	0.78	0.76	7.11
8/22 - 8/23	6.39	5.58	1.30	0.81	7.70

GMD FIELD 7. CORN - ACCO 8951/7951. GRANT CO. 1978.

SEASONAL TOTAL:	MM H_2O
TRANSPIRATION	273.7
ADVECTION	43.1
SOIL EVAPORATION . . .	83.9
ET	400.7
PET	420.7
DRAINAGE	0.0
RUNOFF	0.2

AVERAGE DAILY VALUES
(MM)

MO/DAY-MO/DAY	PET	TRANS	ADV	EVAP	ET
6/19 - 6/25	6.48	1.17	0.27	1.33	2.78
6/26 - 7/ 2	8.00	2.58	0.26	2.87	5.71
7/ 3 - 7/ 9	7.60	4.27	0.98	0.94	6.19
7/10 - 7/16	6.85	5.05	1.19	1.72	7.96
7/17 - 7/23	6.24	5.16	1.04	1.08	7.28
7/24 - 7/30	6.99	6.10	0.82	0.89	7.81
7/31 - 8/ 6	4.89	4.18	0.23	0.71	5.12
8/ 7 - 8/13	6.29	5.16	0.62	1.13	6.90
8/14 - 8/20	5.80	4.66	0.50	1.14	6.30
8/21 - 8/21	6.69	5.37	1.61	1.31	8.30

LISTING OF THE SORGHUM EVAPOTRANSPIRATION MODEL

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C============================================================================
C                          EVAPOTRANSPIRATION OF  SORGHUM
C============================================================================
C
       INTEGER  W      ,D      ,CRDFMT(20)      ,MO     ,DY     ,YR      ,
      *WEEKS  ,BEGWK(26,2)/52*0/       ,ENDWK(26,2)/52*0/,DECK ,
      *NODECK
       REAL    IPET    ,TTET   ,CTMAX  ,CTMIN  ,SUMEV  ,EVAPC  ,EVAPF   ,
      *SM90   ,DEP90   ,TAU    ,TTRNSP ,TADV   ,TEVAP  ,TDRN   ,TRNCF   ,
      *DEP150 ,TMAX    ,TMIN   ,SR     ,LAI    ,RN     ,IRR    ,TRANSP  ,
      *ADV    ,EVAP    ,ET     ,PET    ,DRN    ,RNOF   ,CGDD   ,PREC    ,
      *WTR    ,TMX     ,TMN    ,SMI90  ,FC90   ,AWC90  ,SMI150 ,FC150   ,
      *AWC150 ,C       ,U      ,TITLE(20)      ,WPET           ,T       ,
      *WINS   ,WADV    ,WEVAP  ,WET    ,RAIN   ,SM150  ,
      *ADINS(26)/26*0./        ,ADADV(26)/26*0./        ,ADEVAP(26)/26*0./,
      *ADPET(26)/26*0./        ,ADET(26)/26*0./
C
C*----------> (NODECK IS THE NUMBER OF DECKS (FIELDS) TO BE RUN ) <-----------*
C
       READ (5,511) NODECK
C
C*----------> (CRDFMT IS A FORMAT USED TO READ THE DATA CARDS    ) <-----------*
C
       READ (5,500) (CRDFMT(N),N=1,20)
       DO 901 DECK=1,NODECK
C
C*----------> (    READ THE TITLE FOR EACH FIELD                  ) <-----------*
C
       READ (5,501) (TITLE(M),M=1,20)
C
C*----------> (     READ THE FIELD CONSTANTS                      ) <-----------*
C
       READ (5,506) SMI90,FC90,AWC90,SMI150,FC150,AWC150,C,U
C
C*----------> (              PRINT THE TITLE                      ) <-----------*
C
    5  WRITE (6,502) TITLE
C
C*----------> (            INITIALIZE VARIABLES.                  ) <-----------*
C
       SUMEV=U
       T=0.
       TADV=0.
       TDRN=0.
       TEVAP=0.
       TDRN=0.
       TPET=0.
       TRANSP=0.
       TRNOF=0.
       TTET=0.
       TTRNSP=0.
       WEEKS=0
C
C*----------> (     PRINT THE HEADING FOR THE DAILY DATA          ) <-----------*
C
       WRITE (6,503)
C
C*----------> (    PROCESS THE DATA IN WEEKLY AND DAILY LOOPS     ) <-----------*
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C
      DO 100 W=1,26
      WADV=0.
      WET=0.
      WEVAP=0.
      WPET=0.
      WTNS=0.
      DO 99 D=1,7
      READ (5,CRDFMT) MO,DY,YR,TMAX,TMIN,SR,LAI,RAIN,IRR
C
C*----------> (A BLANK CARD IS NEEDED TO SIGNAL THE END OF THE  ) <------------*
C*----------> (FIELD'S DAILY DATA.  WHEN THIS BLANK CARD IS READ) <------------*
C*----------> (SR WILL BE 0, WHICH COULD NEVER HAPPEN OTHERWISE,) <------------*
C*----------> (THIS TEST WILL DROP THROUGH AND THE AVERAGE      ) <------------*
C*----------> (DAILY VALUES FOR THE LAST WEEK WILL BE CALCULATED) <------------*
C
      IF (SR.GT.0.0)GO TO 15
C
C*----------> (IF D IS EQUAL TO 1 WHEN THE BLANK CARD IS READ,  ) <------------*
C*----------> (IT WOULD MEAN THAT THE DATA ENDED ON A WEEK      ) <------------*
C*----------> (BOUNDARY, THEREFORE NO FURTHER CALCULATIONS NEED ) <------------*
C*----------> (TO BE MADE AND WE CAN BRANCH OUT OF THE LOOP.    ) <------------*
C
      IF(D.EQ.1)GO TO 900
      ADPET(W)=WPET/(D-1)
      ADTNS(W)=WTNS/(D-1)
      ADADV(W)=WADV/(D-1)
      ADEVAP(W)=WEVAP/(D-1)
      ADET(W)=WET/(D-1)
      GO TO 900
   15 IF(D.EQ.1)GO TO 20
      IF(D.EQ.7)GO TO 21
      GO TO 24
   20 WEEKS =WEEKS+1
      BEGWK(WEEKS,1)=MO
      BEGWK(WEEKS,2)=DY
      GO TO 24
   21 ENDWK(WEEKS,1)=MO
      ENDWK(WEEKS,2)=DY
C
C*----------> (              CALCULATE NET RADIATION.           ) <------------*
C
   24 IF (LAI.LT.3.)RN=(0.73*SR)-51.
      IF (LAI.GE.3.)RN=(0.84*SR)-132.
C*----------> (CALL SUBROUTINE TO CONVERT TEMPERATURES FROM      ) <------------*
C
C*----------> (FARENHEIT TO CENTIGRADE.  THEN CALCULATE THE      ) <------------*
C*----------> (                 TEMPERATURE FUNCTION.            ) <------------*
C
   25 CALL CNTGR(TMAX,TMIN,CTMAX,CTMIN)
      TAVG=(CTMAX+CTMIN)/2.
      FTEMP=(.016*TAVG)-15.E-6((*(TAVG**3)+(TAVG**4)/(1.E7))+.4
C
C*----------> (CALCULATE POTENTIAL EVAPOTRANSPIRATION,           ) <------------*
C*----------> (TRANSPIRATION, AND ADVECTION.                     ) <------------*
C
      PET=1.28*FTEMP*RN/59.
      TAU=EXP(-.39*LAI)
      IF(TAU.GT.1.)TAU=1.
      IF(LAI.GT.3.)TRANSP=(1.28-TAU)*FTEMP*RN/59.
```

```
      IF(LAI.LE.3.)TRANSP=1.4*(1-TAU)*FTEMP*RN/59.
      IF(TMAX.LE.91.)ADV=0.
      IF(91..LT.TMAX.AND.TMAX.LT.97.)ADV=.1*(TMAX-91.)*TRANSP*5./9.
      IF(TMAX.GE.97.)ADV=0.3*TRANSP
C
C*----------> (CALCULATE EFFECTIVE PRECIPITATION AND RUNOFF.    I <-----------*
C
   50 IF(RAIN.LE.25.4)PREC=RAIN
      IF(RAIN.GT.25.4)PREC=(RAIN/25.4)**.75*25.4
   60 RNOF=RAIN-PREC
      TRNOF=TRNOF+RNOF
      WTR=PREC+IRR
C
C*----------> (CALCULATE EVAPORATION FROM THE SOIL SURFACE.     I <-----------*
C
      EVAPC=TAU*FTEMP*RN/59.
      IF(PET.LE.0.)GO TO 62
      IF(WTR.GT.6.)GO TO 64
   61 IF(SUMEV.LT.U)GO TO 66
      T=T+1.
      EVAPF=C*(SQRT(T)-SQRT(T-1.))
      IF(EVAPF.GT.EVAPC)GO TO 66
      EVAP=EVAPF
      GO TO 70
   62 TRANSP=0.
      PET=0.
      ADV=0.
      EVAP=0.
      IF(WTR.LE.6.)GO TO 70
      SUMEV=0.
      T=0.
      GO TO 70
   64 SUMEV=0.
      T=0.
   66 EVAP=EVAPC
   70 SUMEV=SUMEV+EVAP
C
C*----------> (CALCULATE THE SOIL MOISTURE BALANCE.             I <-----------*
C
      ET=TRANSP+EVAP+ADV
      SM90=SMI90-ET+WTR
      IF(SM90.GT.FC90)SM90=FC90
      DEP90=((FC90-SM90)/AWC90)*100
      SMI90=SM90
      SM150=SMI150-ET+WTR
      IF(SM150.LE.FC150)GO TO 75
      DRN=SM150-FC150
      TDRN=TDRN+DRN
      SM150=FC150
   75 DEP150=((FC150-SM150)/AWC150)*100
      SMI150=SM150
C
C*----------> (      PRINT THE DAILY VALUES                      I <-----------*
C*----------> (WE CHOSE TO CONSIDER A 150 CM ROOT ZONE WHEN      ) <-----------*
C*----------> (PRINTING SOIL MOISTURE VALUES.  A 90 CM CAN BE    ) <-----------*
C*----------> (SELECTED IF IT SEEMS MORE APPROPRIATE.            ) <-----------*
C
   80 WRITE (6,507) MO,DY,TMAX,TMIN,SR,LAI,IRR,RAIN,PET,TRANSP,ADV,EVAP,
     *ET,SM150,DEP150
      TTRNSP=TTRNSP+TRANSP
```

```
      TADV=TACV+ADV
      TEVAP=TEVAP+EVAP
      TTET=TTET+ET
      TPET=TPET+PET
      WPET=WPET+PET
      WTNS=WTNS+TRANSP
      WADV=WADV+ADV
      WEVAP=WEVAP+EVAP
      WET=WET+ET
      NDDY=DY
      NDMO=MD
   99 CONTINUE
      ADPET(W)=WPET/7
      ADTNS(W)=WTNS/7
      ADADV(W)=WADV/7
      ADEVAP(WI=WEVAP/7
      ADET(WI=WET/7
  100 CONTINUE
  900 ENDWK(WEEKS,1)=NDMO
      ENDWK(WEEKS,2)=NDDY
C
C*----------> (      PRINT THE SUMMARY OF SEASON TOTALS           ) <-----------*
C
      WRITE (6,510) (TITLE(M),M=1,20)
      WRITE (6,505) TTRNSP,TADV,TEVAP,TTET,TPET,TDRN,TRNDF
C
C*----------> (      PRINT THE AVERAGE DAILY VALUES FCR EACH WEEK) <-----------*
C
      WRITE (6,504)
      IF(ENDWK(WEEKS,1).NE.0)GO TO 101
      ENDWK(WEEKS,1)=MD
      ENDWK(WEEKS,2)=DY
  101 DO 103 I=1,WEEKS
      WRITE (6,508) BEGWK(I,1),BEGWK(I,2),ENDWK(I,1),ENDWK(I,2),
     *ADPET(I),ADTNS(I),ADADV(I),ADEVAP(I),ADET(I)
  103 CONTINUE
  901 CONTINUE
      WRITE (6,509)
C
C*----------> (  ALL OF THE FORMATS, BOTH READ AND WRITE, WERE  ) <-----------*
C*----------> (  COLLECTED AND PUT HERE.                          ) <-----------*
C
  500 FORMAT(20A4)
  501 FORMAT(20A4)
  502 FORMAT ('1',/,41X,20A4)
  503 FORMAT     (/,10X,'MAX',7X,'MIN',7X,'SOLAR',63X,'SOIL',15X,'SM',
     *8X,'%DEPL',/,' MO DAY',3X,2('TEMP',6X),' RAD.',5X,'LAI',6X,'IRR',
     *7X,'PRECIP',4X,'PET',7X,'TRANS',5X,'ADV',6X,'EVAP',6X,'ET',7X,
     *'150',8X,'150',/,10X,'(F)',7X,'(F)',6X,'(LGY/D)',13X,'(MM)',
     *7X, '(MM)',
     *5X,'(MM)',2(6X,'(MM)'),5X,'(MM)',5X,'(MM)',6X,'(MM)',
     */,' ',132('-'))
  504 FORMAT (////,55X,'AVERAGE DAILY VALUES',/,62X,' (MM)',/,
     */,37X,' MO/DAY-MO/DAY',6X,'PET',5X,'TRANS',5X,'ADV',5X,'EVAP',
     *6X,'ET',/,36X,61('-'))
  505 FORMAT  (' ',50X,'SEASONAL TOTAL:', 7X,' MM H C',/,77X,' 2',/,
     *49X,' ',30('-'),/,
     *51X,'TRANSPIRATION  . . . . .', F7.1,/,51X,'ADVECTION  . . . . . . .',
     * F7.1,/,51X,'SOIL EVAPORATION . . . .', F7.1,/,51X,
     *'ET . . . . . . . . . . . .', F7.1,/,51X,'PET  . . . . . . . . . .',
```

```
     * F7.1,/,51X,'DRAINAGE . . . . . . . .', F7.1,/,51X,
     *'RUNOFF . . . . . . . . .',F7.1)
 506 FORMAT (F5.0,F7.0,F7.0,F6.0,2F7.0,F6.0,F6.0)
 507 FORMAT  (I2,I4,F8.0,F10.0,F11.0,F9.3,F9.1,F11.1,F9.2,F11.2,F9.2,
     *F9.2,F9.2,F10.0,F11.1)
 508 FORMAT (38X,I2,'/',I2,' -',I2,'/',I2,F10.2,F10.2,F8.2,F9.2,F9.2)
 509 FORMAT ('1')
 510 FORMAT  ('1',4(/,'-'),41X,20A4,//)
 511 FORMAT(20(I2,1X))
     STOP
     END

     SUBROUTINE CNTGR(TMAX,TMIN,CTMAX,CTMIN)
     CTMAX=(TMAX-32)*5/9
     CTMIN=(TMIN-32)*5/9
     RETURN
     END

$ENTRY
```

RESULTS FOR SORGHUM FIELDS

GMO FIELD F. SORGHUM - NC+ 2805. FINNEY CO. 1978.

MO	DAY	MAX TEMP (F)	MIN TEMP (F)	SOLAR RAD. (LGY/D)	LAI	IRR (MM)	PRECIP (MM)	PET (MM)	TRANS (MM)	ADV (MM)	SOIL EVAP (MM)	ET (MM)	SM 150 (MM)	%DEPL 150
6	23	92.	64.	674.	0.233	0.0	0.0	7.35	0.70	0.04	3.53	4.27	432.	39.9
6	24	100.	70.	674.	0.268	0.0	0.0	7.83	0.86	0.26	1.46	2.58	430.	40.7
6	25	104.	65.	701.	0.303	0.0	0.0	8.15	1.00	0.30	1.12	2.42	427.	41.4
6	26	93.	64.	703.	0.338	0.0	0.0	7.74	1.05	0.12	0.95	2.12	425.	42.1
6	27	84.	65.	705.	0.373	0.0	15.2	7.47	1.11	0.00	5.05	6.16	434.	39.3
6	28	90.	64.	577.	0.408	0.0	3.8	6.11	0.99	0.00	4.07	5.06	433.	39.7
6	29	92.	64.	687.	0.462	0.0	0.0	7.51	1.36	0.08	4.90	6.34	427.	41.6
6	30	90.	64.	653.	0.517	0.0	0.0	7.03	1.41	0.00	3.53	4.94	422.	43.2
7	1	95.	64.	564.	0.571	0.0	0.0	6.09	1.34	0.30	1.46	3.10	419.	44.2
7	2	95.	64.	674.	0.625	0.0	0.0	7.45	1.78	0.39	1.12	3.29	415.	45.2
7	3	98.	67.	687.	0.680	0.0	0.0	7.82	2.01	0.60	0.95	3.56	412.	46.3
7	4	98.	70.	714.	0.734	0.0	0.0	8.28	2.27	0.68	0.83	3.78	408.	47.5
7	5	100.	69.	708.	0.788	0.0	0.0	8.24	2.40	0.72	0.75	3.87	404.	48.7
7	6	98.	64.	653.	0.843	0.0	0.0	7.29	2.25	0.68	0.69	3.62	401.	49.8
7	7	88.	63.	699.	0.897	0.0	0.0	7.47	2.43	0.00	0.64	3.08	398.	50.8
7	8	102.	66.	482.	0.957	0.0	0.0	5.30	1.82	0.55	0.61	2.57	395.	51.7
7	9	82.	59.	325.	1.017	0.0	0.0	2.89	1.04	0.00	0.57	1.61	393.	52.2
7	10	82.	59.	699.	1.077	0.0	0.0	7.12	2.69	0.00	0.54	3.23	390.	53.2
7	11	96.	65.	599.	1.137	0.0	7.6	6.59	2.60	0.72	3.30	6.62	391.	52.9
7	12	102.	72.	654.	1.197	135.7	2.3	7.71	3.17	0.95	3.78	7.50	521.	12.3
7	13	82.	64.	238.	1.257	0.0	0.0	1.55	0.83	0.00	0.93	1.77	519.	12.8
7	14	100.	73.	656.	1.501	0.0	0.0	7.70	3.76	1.13	3.35	8.24	511.	15.4
7	15	97.	64.	704.	1.744	0.0	0.0	7.89	4.29	1.29	3.12	8.70	502.	18.1
7	16	96.	64.	574.	1.988	0.0	0.0	6.25	3.71	1.03	2.25	6.59	495.	20.3
7	17	105.	71.	674.	2.231	0.0	0.0	8.05	5.15	1.55	2.63	9.33	486.	23.2
7	18	99.	65.	668.	2.475	0.0	0.0	7.55	5.15	1.54	1.46	8.15	478.	25.8
7	19	96.	68.	449.	2.718	0.0	2.8	4.83	3.48	1.04	1.12	5.64	475.	26.6
7	20	94.	68.	438.	2.962	0.0	0.0	4.60	3.47	0.58	0.95	5.00	470.	28.2
7	21	98.	60.	616.	3.364	0.0	2.5	6.48	5.12	1.54	0.83	7.49	465.	29.8
7	22	80.	59.	665.	3.765	0.0	0.0	6.54	5.37	0.00	0.75	6.12	459.	31.7
7	23	80.	56.	564.	4.167	0.0	0.0	5.16	4.37	0.00	0.69	5.06	454.	33.3
7	24	92.	57.	676.	4.568	0.0	0.0	7.03	6.10	0.34	0.64	7.09	446.	35.5
7	25	95.	60.	687.	4.970	0.0	0.0	7.38	6.55	1.46	0.61	8.61	438.	38.2
7	26	95.	55.	673.	5.371	0.0	0.0	7.02	6.34	1.41	0.57	8.33	430.	40.8
7	27	90.	56.	673.	5.773	0.0	0.0	6.88	6.32	0.00	0.54	6.86	423.	42.9
7	28	96.	60.	676.	5.688	0.0	0.0	7.26	6.65	1.85	0.52	9.01	414.	45.7
7	29	93.	54.	650.	5.603	0.0	0.0	6.61	6.03	0.67	0.50	7.20	406.	48.0
7	30	90.	55.	520.	5.518	0.0	4.6	4.82	4.38	0.00	0.44	4.82	406.	48.0
7	31	93.	61.	624.	5.433	0.0	0.0	6.47	5.87	0.65	0.46	6.58	399.	50.2
8	1	94.	64.	624.	5.348	0.0	0.0	6.60	5.56	0.99	0.45	7.40	392.	52.5
8	2	90.	57.	662.	5.263	0.0	0.0	6.77	6.09	0.00	0.43	6.53	385.	54.6
8	3	63.	54.	194.	5.178	0.0	31.8	0.42	0.38	0.00	0.04	0.42	415.	45.3
8	4	67.	53.	205.	5.093	0.0	1.3	0.55	0.50	0.00	0.06	0.55	416.	45.1
8	5	80.	55.	601.	5.008	0.0	0.0	5.60	4.98	0.00	0.62	5.60	410.	46.8
8	6	86.	63.	657.	4.923	0.0	0.0	6.77	5.99	0.00	0.78	6.77	403.	48.9
8	7	85.	59.	419.	4.839	0.0	0.0	3.46	3.05	0.00	0.41	3.46	400.	50.0
8	8	86.	57.	630.	4.754	0.0	0.0	6.22	5.46	0.00	0.76	6.22	394.	52.0
8	9	86.	58.	639.	4.669	0.0	0.0	6.37	5.56	0.00	0.81	6.37	387.	54.0
8	10	94.	62.	610.	4.584	0.0	0.0	6.34	5.51	0.92	0.83	7.26	380.	56.2
8	11	96.	60.	622.	4.728	0.0	0.0	6.51	5.70	1.58	0.80	8.09	372.	58.8
8	12	94.	61.	620.	4.873	0.0	0.0	6.45	5.70	0.95	0.75	7.40	365.	61.1
8	13	94.	76.	631.	5.017	0.0	0.0	7.07	6.29	1.05	0.78	8.12	356.	63.6
8	14	92.	53.	678.	5.162	0.0	0.0	6.92	6.19	0.34	0.72	7.26	349.	65.9

8	15	85.	55.	650.	5.306	0.0	0.0	6.38	5.75	0.00	0.63	6.38	343.	67.9
8	16	97.	59.	616.	5.165	0.0	0.0	6.42	5.75	1.73	0.67	8.15	335.	70.4
8	17	102.	60.	642.	5.024	0.0	0.0	6.98	6.21	1.86	0.77	8.84	326.	73.2
8	18	84.	55.	610.	4.883	0.0	0.0	5.83	5.16	0.00	0.68	5.83	320.	75.0
8	19	78.	56.	578.	4.742	0.0	0.0	5.28	4.63	0.00	0.65	5.28	315.	76.6
8	20	88.	61.	553.	4.601	0.0	1.3	5.36	4.66	0.00	0.70	5.36	311.	77.9
8	21	99.	68.	595.	4.460	0.0	0.0	6.44	5.56	1.67	0.88	8.11	303.	80.5
8	22	94.	69.	583.	4.319	0.0	0.0	6.16	5.26	0.88	0.89	7.03	296.	82.7
8	23	97.	68.	581.	4.178	0.0	0.0	6.18	5.24	1.57	0.95	7.75	288.	85.1
8	24	95.	68.	566.	4.150	130.5	0.0	5.91	4.99	1.11	0.92	7.02	411.	46.5

GMD FIELD F. SORGHUM - NC+ 2805. FINNEY CO. 1978.

SEASONAL TOTAL:	MM H_2O
TRANSPIRATION	247.8
ADVECTION	37.1
SOIL EVAPORATION . . .	78.2
ET	363.1
PET	398.9
DRAINAGE	0.0
RUNOFF	1.7

AVERAGE DAILY VALUES
(MM)

MO/DAY-MO/DAY	PET	TRANS	ADV	EVAP	ET
6/23 - 6/29	7.45	1.01	0.11	3.01	4.14
6/30 - 7/ 6	7.46	1.52	0.48	1.33	3.74
7/ 7 - 7/13	5.57	2.08	0.32	1.48	3.88
7/14 - 7/20	6.70	4.14	1.17	2.13	7.44
7/21 - 7/27	6.64	5.74	0.68	0.66	7.08
7/28 - 8/ 3	5.56	5.05	0.59	0.41	6.05
8/ 4 - 8/10	5.04	4.44	0.13	0.61	5.17
8/11 - 8/17	6.67	5.54	1.07	0.73	7.75
8/18 - 8/24	5.88	5.C7	0.75	0.81	6.63

GMD FIELD A. SORGHUM - PIONEER 8311. HODGEMAN CO. 1978.

SEASONAL TOTAL:	MM H_2O
TRANSPIRATION	227.8
ADVECTION	44.1
SOIL EVAPORATION . . .	49.7
ET	321.7
PET	368.4
DRAINAGE	29.5
RUNOFF	0.0

AVERAGE DAILY VALUES
(MM)

MO/DAY-MO/DAY	PET	TRANS	ADV	EVAP	ET
6/29 - 7/ 5	7.39	1.11	0.33	1.27	2.72
7/ 6 - 7/12	6.88	1.74	0.34	0.53	2.61
7/13 - 7/19	6.39	2.91	0.87	0.40	4.19
7/20 - 7/26	6.60	4.65	0.90	1.68	7.23
7/27 - 8/ 2	6.67	5.91	1.17	0.77	7.85
8/ 3 - 8/ 9	4.56	4.20	0.03	0.35	4.59
8/10 - 8/16	6.89	6.C4	1.46	0.84	8.34
8/17 - 8/23	6.29	5.22	0.97	1.07	7.26
8/24 - 8/24	6.62	5.33	1.60	1.29	8.22

GMD FIELD B. SORGHUM - ACCO GR1028. GRAY CO. 1978.

SEASONAL TOTAL:	MM H_2O
TRANSPIRATION	188.9
ADVECTION	28.0
SOIL EVAPORATION . . .	74.1
ET	291.0
PET	301.0
DRAINAGE	0.0
RUNOFF	0.0

AVERAGE DAILY VALUES
(MM)

MO/DAY-MO/DAY	PET	TRANS	ADV	EVAP	ET
7/ 5 - 7/11	6.06	1.80	0.32	1.33	3.46
7/12 - 7/18	6.73	3.28	0.94	1.32	5.54
7/19 - 7/25	6.12	3.67	0.53	2.18	6.38
7/26 - 8/ 1	6.59	4.89	0.65	1.66	7.20
8/ 2 - 8/ 8	4.26	3.36	0.00	0.90	4.26
8/ 9 - 8/15	6.01	4.62	0.58	1.39	6.59
8/16 - 8/22	6.32	4.70	0.77	1.56	7.03
8/23 - 8/23	6.48	4.69	1.41	1.74	7.83

GMD FIELD C. SORGHUM - PIONEER 8501. GRAY CO. 1978.

SEASONAL TOTAL:	MM H_2O
TRANSPIRATION	214.6
ADVECTION	31.5
SOIL EVAPORATION . . .	43.7
ET	289.8
PET	292.9
DRAINAGE	0.0
RUNOFF	0.0

AVERAGE DAILY VALUES
(MM)

MO/DAY-MO/DAY	PET	TRANS	ADV	EVAP	ET
7/ 5 - 7/11	6.41	2.21	0.39	1.33	3.93
7/12 - 7/18	6.73	4.18	1.20	0.55	5.93
7/19 - 7/25	5.85	4.81	0.69	0.96	6.46
7/26 - 8/ 1	6.52	5.64	0.76	0.88	7.28
8/ 2 - 8/ 8	4.26	3.66	0.00	0.60	4.26
8/ 9 - 8/15	6.01	5.09	0.64	0.92	6.65
8/16 - 8/22	6.07	5.06	0.83	1.01	6.90

GMO FIELO D. SORGHUM - NK2778. SEWARO CO. 1978.

SEASONAL TOTAL:	MM H_2O
TRANSPIRATION	149.0
AOVECTION	27.2
SOIL EVAPORATION . . .	61.4
ET	237.6
PET	330.8
ORAINAGE	9.5
RUNOFF	0.8

AVERAGE CAILY VALUES
(MM)

MO/OAY-MO/OAY	PET	TRANS	AOV	EVAP	ET
6/30 - 7/ 6	7.78	0.44	0.13	1.52	2.09
7/ 7 - 7/13	6.12	0.74	0.14	1.38	2.26
7/14 - 7/20	6.63	2.03	0.61	0.34	2.97
7/21 - 7/27	7.15	3.54	0.64	1.84	6.01
7/28 - 8/ 3	6.18	3.58	0.67	1.28	5.53
8/ 4 - 8/10	5.40	4.26	0.21	1.13	5.60
8/11 - 8/17	7.04	5.90	1.49	1.14	8.53
8/18 - 8/18	6.63	5.61	0.00	1.02	6.63

GMD FIELD E. SORGHUM - NK2778. SEWARD CO. 1978.

SEASONAL TOTAL:	MM H_2O
TRANSPIRATION	133.7
ADVECTION	23.6
SOIL EVAPORATION . . .	76.7
ET	234.0
PET	332.6
DRAINAGE	32.8
RUNOFF	0.8

AVERAGE DAILY VALUES
(MM)

MO/DAY-MO/DAY	PET	TRANS	ADV	EVAP	ET
6/30 - 7/ 6	7.78	0.33	0.10	1.66	2.09
7/ 7 - 7/13	6.12	0.55	0.10	1.52	2.17
7/14 - 7/20	6.63	1.41	0.42	0.40	2.23
7/21 - 7/27	7.15	2.80	0.51	3.46	6.77
7/28 - 8/ 3	6.04	3.58	0.73	0.89	5.60
8/ 4 - 8/10	5.57	4.17	0.19	1.40	5.76
8/11 - 8/17	7.24	5.19	1.31	1.35	7.86
8/18 - 8/18	6.79	4.72	0.00	1.96	6.68

EVALUATION OF AN EVAPOTRANSPIRATION MODEL

FOR CORN AND SORGHUM

by

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Evapotranspiration (ET) models can be used for irrigation scheduling programs, but a simple, reliable estimate of daily ET is necessary. Many models require climatic data that are not routinely measured by the National Weather Service, limiting application of the models. We have developed and tested an ET model which requires maximum and minimum temperature, solar radiation, precipitation (or irrigation), and leaf area index. These data are available from weather reporting stations, or are easily measured. Model outputs are potential evapotranspiration, transpiration, evaporation, runoff, drainage, and moisture stored in the soil profile. Kanemasu (1976) and Rosenthal (1978) have previously shown that this model satisfactorily estimates ET in Kansas, but widespread use of the model has not yet been implemented in the state. Many potential users of the ET model do not have access to computer facilities. Therefore, we simplified the model to run on a programmable calculator.

The simplified model was tested on irrigated corn and sorghum on ten farms in southwestern Kansas. Model estimates were compared to gravimetric measurements of soil moisture. The t-test of the mean difference (D) of estimated and observed soil moisture indicate a mean difference of zero at $P < .025$ for corn and $P < .20$ for sorghum.

Many researchers have shown that limited irrigation can be practiced without reducing yields, if water applications are scheduled to avoid moisture stress at critical periods of crop growth. Reduced pumpage is desirable, to limit the depletion of water and fuel supplies, and to reduce the costs of irrigating a crop. This ET model, if implemented on a regional basis, can provide information necessary for an irrigation scheduling program.